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Technical Report

No. 13515

AGT 1500 POWERPACK IMPROVEMENT PROJECT (M1 TMEPS)

CONTRACT NUMBER DAAE07-87-C-R006

MARCH 1991

VOLUME I OF II

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By GDLS DOCUMENT NO. DB-87-04057-001A

U.S. ARMY TANK-AUTOMOTIVE COMMAND
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY N/A 2b. DECLASSIFICATION/DOWNGRAING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) DB-87-04057-001A	5. MONITORING ORGANIZATION REPORT NUMBER(S) DB-87-04057-001 TACOM T.R. 13515
6a. NAME OF PERFORMING ORGANIZATION General Dynamics Land Systems Division 6b. OFFICE SYMBOL (If Applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Tank Automotive Command
6c. ADDRESS (City, State and ZIP Code) 38500 Mound Road Sterling Hts, MI 48310	7b. ADDRESS (City, State and ZIP Code) U. S. Army Tank Automotive Command Warren, Michigan 48397-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If Applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAE07-87-C-R006
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
AGT 1500 Powerpack Improvement Project (M1 TMEPS)
Scientific and Technical Report

12. PERSONAL AUTHOR(S)
Edwards Jonathan Robert

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 5/87 TO 6/90	1990, 10, 25	178

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	TMPES, Transverse Mounted Engine Propulsion System, Automotive Test Rig, Self Cleaning Air Filter, Vehicle Accessory Gearbox

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Transverse Mounted Engine Propulsion System Scientific and Technical Report presents the design, trade-offs, performance and cost data developed under contract DAAE-07-87-C-R006. This report contains design summaries for all automotive hardware designed and integrated into the automotive test rig. Follow-on goals are also presented for future design activities.

20. DISTRIBUTION/AVAILABILTY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified

22a. NAME OF RESPONSIBILE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
M. Jefferson	574-7513	AMSTA-RGR

DD FORM 1473, 84 MAR

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SUMMARY

The Transverse Mounted Engine Propulsion System (TMEPS) is a low cost, low risk evolutionary step for powerpack design. TMEPS offers an integrated, compact automotive system including:

- o Compact space efficient powerpack.
- o Improved fuel efficient transversely mounted AGT-1500 engine.
- o XT1100-3 seven speed transmission with transverse gearbox.
- o A new compact mounted selfcleaning air filtration system.
- o Integrated demand responsive powerpack cooling system with a dynamic increase in heat rejection.
- o Integrated underarmor auxiliary power unit for reduced fuel consumption, longer engine life, and independent Nuclear, Biological and Chemical (NBC) supply.

TMEPS supports improvement in lethality and survivability by providing the following benefits:

- o As a result of more efficient packaging, the TMEPS Automotive Test Rig (ATR) powerpack opens up 47 cubic feet of usable space in the powerpack compartment, per contractual requirements. The follow-on configuration can provide up to 76 cubic feet of usable space.
- o Improvement in vehicle performance and agility.
- o Improvements in fuel economy over M1A1.
- o Top speed is improved over M1A1.
- o Improved diagnostic/prognostics are incorporated through digital engine and controls.
- o Powerpack commonality is maintained with 90 percent of the engine and 46 percent of the transmission with respect to M1A1 hardware. Fifty-six percent commonality is achievable for the transmission with follow-on configuration.

The TMEPS ATR successfully rolled-out on May 9, 1990. Following break-in testing at the Detroit Arsenal Tank Plant (DATP), the

vehicle was sent to Milford Proving Grounds (MPG). The ATR was subjected to six days of intensive vehicle testing on primary and hilly cross-country roads. The vehicle was then returned to General Dynamics Land Systems (GDLS) for instrumentation removal and vehicle storage.

TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	10
1.1	Background	10
2.0	OBJECTIVES	14
3.0	CONCLUSIONS	15
4.0	RECOMMENDATIONS	17
5.0	DISCUSSION	18
5.1	Concept Description	18
5.1.1	Engine and Air Induction	18
5.1.2	Transmission and Final Drive	22
5.1.3	Auxiliary Power Unit and Accessory Drive	22
5.1.4	Cooling and Exhaust System	25
5.1.5	Hydraulic System	25
5.1.6	Fuel System	25
5.1.7	Electrical System	25
5.1.8	Driver's Control System	25
5.1.9	Vehicle Structure	31
5.1.10	Life Cycle Cost	31
5.2	Design	31
5.2.1	Engine and Air Induction	31
5.2.2	Transmission and Final Drive	55
5.2.3	Auxiliary Power Unit and Accessory Drive	71
5.2.4	Cooling and Exhaust System	86
5.2.5	Hydraulic System	101
5.2.6	Fuel System	113
5.2.7	Electrical System	118
5.2.8	Driver's Control System	132
5.2.9	Structures	136
5.3	Vehicle Performance	143
5.3.1	Performance Goals	143
5.3.2	Automotive Performance	143
5.4	Life Cycle Cost	154

TABLE OF CONTENTS (Cont.)

Section	Title	Page
5.4.1	Introduction	154
5.4.2	LCC Methodology	154
5.4.3	LCC Assumptions	161
5.4.4	LCC Results	162
5.4.5	LCC Summary	166
DISTRIBUTION LIST		DIST. 1
APPENDIX I	TME Interchangeability Demonstration Test Report No. LYC 90-18	
APPENDIX II	AGT 1500A TACOM TME Fuel Economy Demonstration Test Engine T202N Report No. LYC 88-39	
APPENDIX III	Final Report for the Development of a Rotating Element Self-Cleaning Air Filter (RESCAF)	

Vol. 2

LIST OF ILLUSTRATIONS

Figure	Title	Page
1-1.	M1 Current and TMEPS Propulsion Systems Installation	11
5-1.	TMEPS Engine Compartment	19
5-2.	Engine (AGT 1500) and Air Induction Installation	20
5-3.	Engine Hardware Improvement	21
5-4.	Transmission (XT1100) Installation	23
5-5.	Auxiliary Power Unit and Accessory Drive Installation	24
5-6.	Cooling and Exhaust System Installation	26
5-7.	Hydraulic System Installation	27
5-8.	Fuel System Installation	28
5-9.	Electrical System Installation	29
5-10.	APU/SCAF Control Panel	30
5-11.	M1 Current and TMEPS Propulsion System Installation	34
5-12.	Self-Cleaning Air Filter (SCAF) System	35
5-13.	Engine Hardware Improvements	36
5-14.	Casting Processes and Benefits of Single Crystal Blade	42
5-15.	Comparison of Present Production Bearing and Improved RAM-D Conrad Bearing Configurations	44
5-16.	Five Percent (5%) and Production HP Nozzle	45
5-17.	Sungear	47
5-18.	RAM-D Position 5 Seal Design	48

LIST OF ILLUSTRATIONS (Cont.)

Figure	Title	Page
5-19.	RAM-D Position 10 Seal Design	49
5-20.	TMEPS XT1100 Transmission	56
5-21.	XT1100 Transmission Envelope	60
5-22.	Range Number Optimization	62
5-23.	XT1100 Final Drive Schematic	63
5-24.	Final Drive Sprocket Design	70
5-25.	Auxiliary Power Unit	72
5-26.	Hydrostatic Drive System	77
5-27.	Direct Drive System	78
5-28.	Multiple Speed Transmission Drive System	79
5-29.	Main Engine Bleed Air and Direct Drive Gearbox System	81
5-30.	Multiple Power Supply System	82
5-31.	Transmission Accessory Drive System	83
5-32.	Direct Drive and Hydrostatic Drive System	84
5-33.	Cooling and Exhaust System	87
5-34.	Single Fan Performance - Static Pressure Versus Flow Rate	90
5-35.	Single Fan Cooler - Heat Rejection Versus Airflow	91
5-36.	Single Fan Cooler - Air Pressure Loss Versus Airflow	92
5-37.	Single Fan Cooler - Oil Pressure Versus Oil Flow	93
5-38.	Cooling System Flowpath	95

LIST OF ILLUSTRATIONS (Cont.)

Figure	Title	Page
5-39.	Seal/Retainer Configuration	99
5-40.	TMEPS Hydraulic System Block Diagram	102
5-41.	Hull/Turret Drive System	103
5-42.	Accessory Cooler and Fan Drive System Flow Block Diagram	105
5-43.	TMEPS Fuel System	114
5-44.	Vehicle Electrical Power Block Diagram	126
5-45.	APU/SCAF Control/Display Panel	127
5-46.	System Block Diagram	128
5-47.	Auxiliary Networks Box	131
5-48.	TMEPS Brake Control System	134
5-49.	Structural Design Modifications	137
5-50.	TMEPS Vehicle Rear View Configuration	139
5-51.	Test Cell Configuration	145
5-52.	Test Cell Installation	146
5-53.	Clean Barrier Filter Media	148
5-54.	Contaminated Barrier Filter Media	149
5-55.	Contaminated Barrier Filter Media	150
5-56.	Life Cycle Cost Comparative Analysis, M1A1 1991, M1A1 1986 and TMEPS	155
5-57.	Hardware Work Breakdown Structure	156
5-58.	Fleet Size and Commonality Perspective, Adding TMEPS Configuration to Fleet	159
5-59.	Life Cycle Cost Methodology	160

LIST OF TABLES

Table	Title	Page
1-2	Engine Improvements	13
5-1	Transmission Features Comparison	64
5-2	Transmission Range Comparison	65
5-3	Air Side Fin Comparison	96
5-4	Grill and Cooling Fan Areas	97
5-5	Induction-Exhaust Cooling, TMEPS/M1A1	98
5-6	TMEPS Electrical Load Analysis	121
5-7	Engine Performance (Comparison)	144
5-8	Engine Power in Vehicle (Installed)	147
5-9	Hardware Commonality	158
5-10	TMEPS Average Unit Production Cost Estimate Summary by WBS	163
5-11	Total Life Cycle Cost Results, M1A1 1991, M1A1 1986 and TMEPS	164
5-12	Comparison of Total Life Cycle Costs, Cost Drivers/Cost Savers	165

1.0 INTRODUCTION

This Science and Technology report on the TMEPS program was prepared by GDLS for the AGT1500 Powerpack Improvement Project in accordance with the requirements of the U.S. Army Tank Automotive Command (TACOM) under contract DAAE07-87-C-R006.

This report presents the conclusions of the program for the period from October 1986 through June 1990. It covers the concepts, program objectives, design, goals, technical approach, tradeoffs, design analysis, seleted design, vehicle performance analysis and the life cycle cost plan.

1.1 Background

A transverse powertrain system study was initiated in July 1985 to enhance the effectiveness of the M1 tank. An unsolicited proposal was submitted in August 1986 and a contract was awarded to GDLS in October 1986. Modification of the ATR vehicle was initiated in November 1986. A design concept, using the M1A1 XT1100-3B four speed hydrokinetic transmission, modified for transverse input, was successfully presented on 12 April 1987 in a preliminary design review (PDR). The contract was subsequently modified in July 1987 to incorporate a seven speed transmission in place of the four speed transmission. The PDR was repeated on 15 December 1987 to include the new XT1100 seven speed transmission. The Government accepted the PDR and agreed to proceed with the critical design phase.

The current propulsion system on the M1 series tank is constructed in a "T" configuration, that is, the engine centerline is perpendicular to the transmission centerline. This configuration was analyzed for improvements in space claim, weight avoidance, efficiency (performance and fuel consumption) and logistics support impacts, resulting in the development of the Transverse Mounted Engine Propulsion System. TMEPS presents an attractive packaging approach and also provides a propulsion system with a significant improvement in performance and growth potential.

A comparison of the present and proposed propulsion system installation is illustrated in Figure 1-1. The compact TMEPS packaging provides an increase in available underarmor space. The improved hardware will provide increased powertrain efficiency, fuel economy, weight reduction potential and auxiliary power utilization.

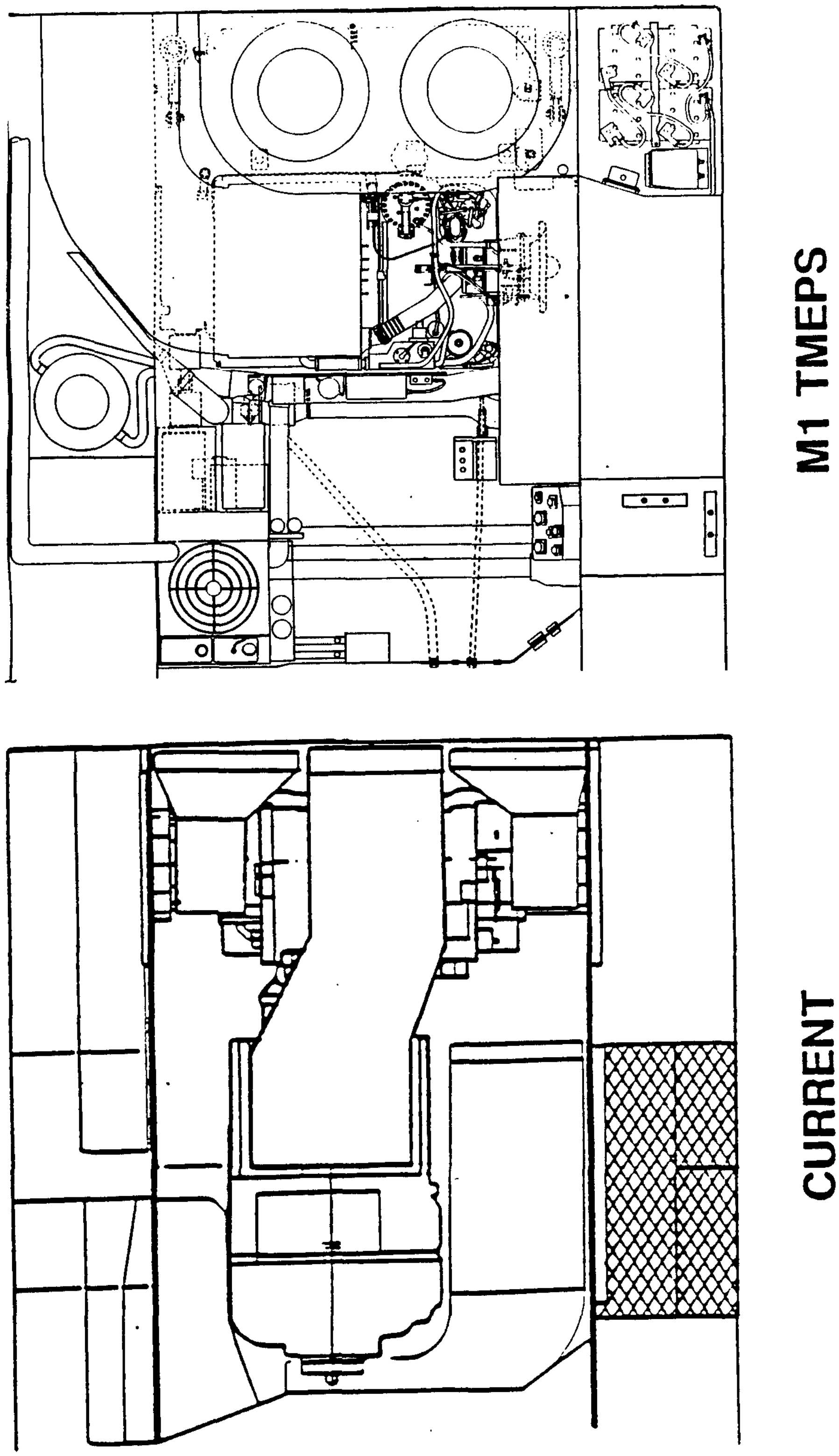


Figure 1-1 M1 Current and TMEPS Propulsion Systems Installation

The vehicles discussed in this report are defined as follows:

- M1A1-86 - 1986 Production vehicle at 63 tons gross vehicle weight (GVW)
- M1A1-91 - TACOM directed 1991 configuration of 1986 production vehicle at 65 tons GVW, which will include 14 RAM-D recommended engine improvements, external auxiliary power unit (APU) and RAM-D self cleaning air filter (SCAF) system.
- TMEPS - The transverse mounted engine propulsion system evolved in 1986 production vehicle at 65 tons GVW which will incorporate nine of the 14 RAM-D engine recommended improvements, and an underarmor full service APU.

The recommended engine improvements are catagorized according to their attributes, as seen in Table 1-2.

The program was performed in three phases: preliminary design concept, detailed design, and fabrication/test. These phases were separated by formal program decision gates e.g. Preliminary Design Review/Critical Design Review (PDR/CDR) that culminated in the fabrication, assembly, and test of the TMEPS ATR.

Table 1-2. Engine Improvements

Engine Improvements	TMEPS	M1A1-91	Attributes
RAM-D			
1. Polygon drive system	X	X	R,C
2. Deep Groove #11 and #13 Conrad bearing races	X	X	R,C
3. Increased (5%) cooling flow HP turbine nozzle	X	X	R,C
4. Increased (root) durability HP turbine blades	NO	X	R,C
5. Alternate (VASCO) Sungear material	X	X	R,C
6. Increased (25%) lubricant flow reduction gearbox	X	X	R,C
7. Non-lube flex coupling powershaft	NO	X	R,C
8. Improved durability combustor	X	X	R,C
9. Improved durability recuperator core	X	X	R,C
10. Metalic piston ring seal #3 bearing	NO	X	R,C
11. Improved durability #5 and #10 oil seals	X	X	R,C
12. Upgraded fuel pump drive coupling	NO	X	R,C
13. Upgraded fuel handling unit	Seals Only	X	R,C
14. Wireless high pressure rotor assembly	NO	X	R,C
PERFORMANCE AND ECONOMY			
1. Improved low pressure compressor	X	NO	F,P
2. Improved high pressure compressor	X	NO	F,P
3. Combustor (attitude 90 degree change)	X	NO	T
4. High pressure turbine nozzle	X	NO	F,P
5. Improved power turbine	X	NO	F,P
6. Low pressure turbine nozzle	X	NO	F,P
7. Revised control schedules	X	NO	F
8. Increased pre-load and improved material recuperator core	X	NO	F,P
9. Reduced volume accessory gearbox	X	NO	T
10. Powerpack/vehicle interfaces	X	NO	T
11. Digital Electronic Control Unit	X	NO	F
12. Self Cleaning Air Filter System	X	NO	P,R,C

Legend - Symbol	Definition
X	in vehicle
T	essential for transverse mounting
F	impacts fuel efficiency
P	impacts vehicle dynamic performance
R	impacts RAM-D
C	impacts LCC

2.0 OBJECTIVES

The objectives of the program were:

- o Experimentally develop, demonstrate and evaluate, in a vehicle, fuel efficiency improvements for the M1A1 Abrams tank transmission and engine.
- o Experimentally incorporate and evaluate, in a vehicle, other selected powerpack components and system improvements which may contribute toward reduction of Life Cycle Costs.
- o Increase powerpack power density.

3.0 CONCLUSIONS

3.1 TMEPS Program

The TMEPS Program demonstrated the viability of transversely mounting the AGT-1500 turbine engine in an Abrams M1A1 vehicle. Through transverse mounting and redesign of automotive systems, engine compartment space was made available for a variety future weapon system upgrades. The automotive test rig was designed and fabricated to evaluate several automotive technology advancements for future application on heavy military vehicles. Results of these technology areas are provided in the following paragraphs.

3.2 Powerpack Integration

The AGT-1500 turbine engine was successfully mounted transversely to an Allison seven speed transmission within an Abrams engine compartment. All necessary support hardware including an underarmor auxiliary power unit were integrated within the chassis without exceeding basic width and height requirements.

3.3 Powerpack Operation

The TMEPS powerpack performed well during its limited test program. Drivability, braking, and control were described as good. Most automotive performance tests were met including creep, turn radius, top speed, and fuel economy. Acceleration and speed on slope exhibited strong performance, but somewhat below epectations. It is believed that these latter characteristics could have been optimized with further testing.

3.4 Self-Cleaning Air Filter

The self-cleaning air filter provided filtered air to the engine, auxiliary power unit and nuclear biological chemical filter system compressor throughout testing. Follow-on design work may reduce the packaging volume of this item.

3.5 Cooling System

The ring cooler design selected performed as designed without failure throughout automotive test rig operation. Adequate cooling was maintained for engine oil, transmission oil and santotrac 50 lubricant. Modulation of the engine and transmission cooling fans was successful in reducing fuel consumption during off peak cooling load heat rejection.

3.6 Auxiliary Power Unit

The John Deere rotary diesel auxiliary power unit was able to provide adequate power to operate the vehicle's nuclear biological chemical system compressor, self-cleaning air filter scavenge fan, main hydraulic pump and provide electrical power to charge the batteries.

3.7 Continuously Variable Transmission

A near constant gearbox speed was maintained by the CVT for all engine operating ranges from idle to maximum speed. This allowed maximum efficiency operation of all accessories regardless of engine speed. This technology will be useful for applications where constant speed drives are necessary.

4.0 RECOMMENDATIONS

The design activity of the TMEPS program culminated in a one week evaluation of the ATR. This was due to funding and schedule constraints. Testing was concentrated on vehicle mobility performance. There was only limited testing of the CVT, APU and SCAF systems. General Dynamics Land Systems recommends a six month follow-on program be funded to provide additional testing of the TMEPS ATR. Testing of the ATR would be performed at General Dynamics Land Systems and at an appropriate heavy tracked vehicle proving grounds. Performance deficiencies will be evaluated and software/hardware corrections will be made during this testing. During this time, detailed evaluations of the CVT, APU and SCAF system will also be performed.

5.0 DISCUSSION

5.1 Concept Description

The TMEPS propulsion system will be installed into the M1A1 vehicle with the capability of vertical installation and removal (Figure 5-1). The M1A1 vehicle was ballasted to a 63 ton GVW. The propulsion system and test rig vehicle incorporated the following modified hardware:

- o Engine and Air Induction
- o Transmission and Final Drives
- o Auxiliary Power Unit and Accessory Drives
- o Cooling and Exhaust System
- o Fuel System
- o Electrical System
- o Hydraulic System
- o Driver's Control System
- o Vehicle Structure

5.1.1 Engine and Air Induction. Figure 5-2 presents the engine and air induction system locations. The prime mover of the TMEPS vehicle is a modified AGT 1500 turbine engine. Approximately 90 percent of all the engine parts are common with the AGT 1500 M1A1 engine. The intent of these changes is to improve power train efficiency, fuel economy, and RAM-D. The major engine hardware modifications are shown in Figure 5-3.

- o Improved High Pressure (HP) Turbine
  - Reduced Blade Cooling
  - Single Crystal Material
  - Trenched Cylinder
  - Increased (Geometric Flow Area) Nozzle
- o Reduced Volume Accessory Gearbox
  - Hydraulic Pump and Pad Removed
- o Digital Electronic Control Unit
  - Schedule changes to improve fuel economy and durability
- o Low Pressure Nozzle
  - Geometric flow area reduced for cycle rematch

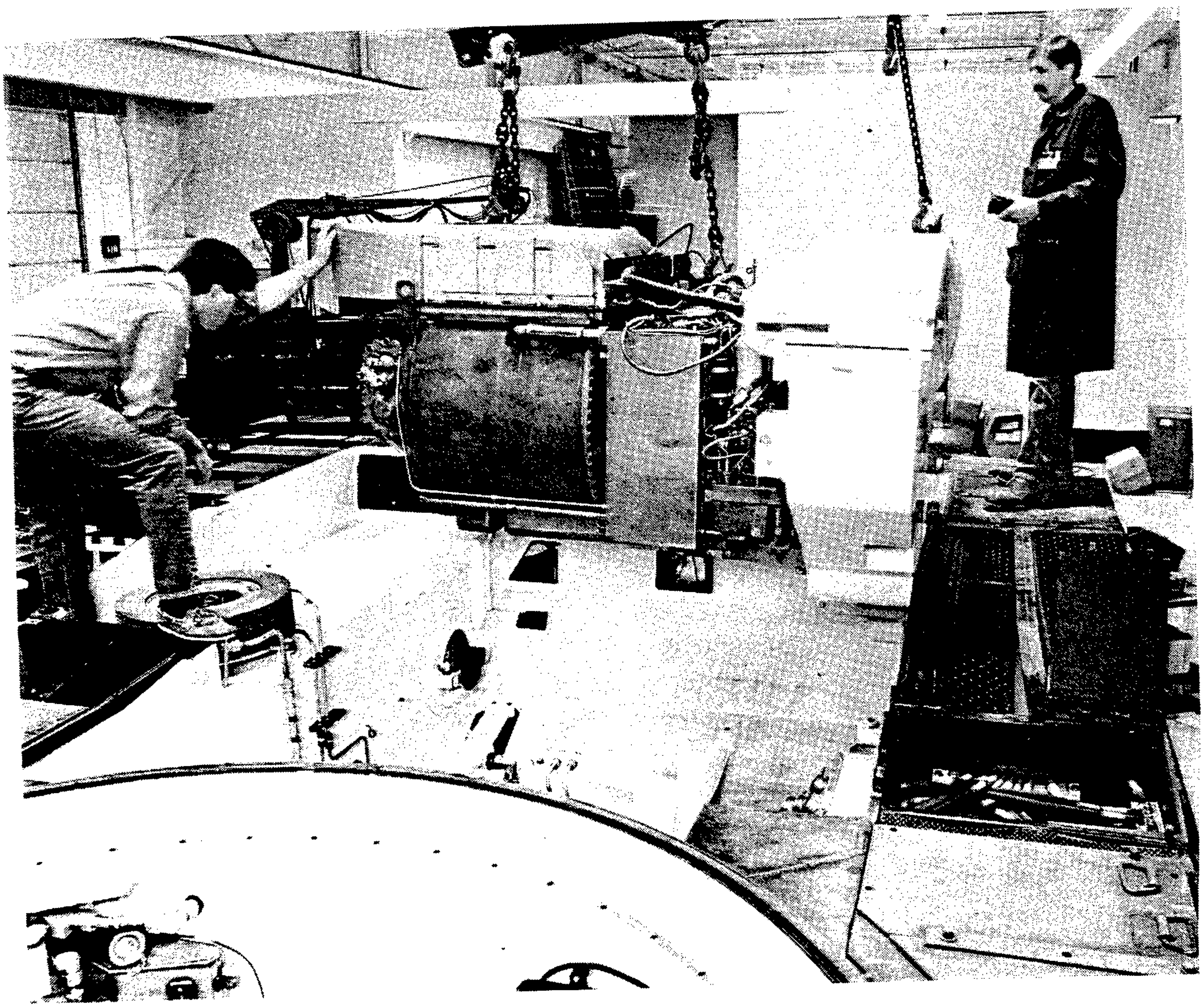


Figure 5-1 TMEPS Engine Compartment

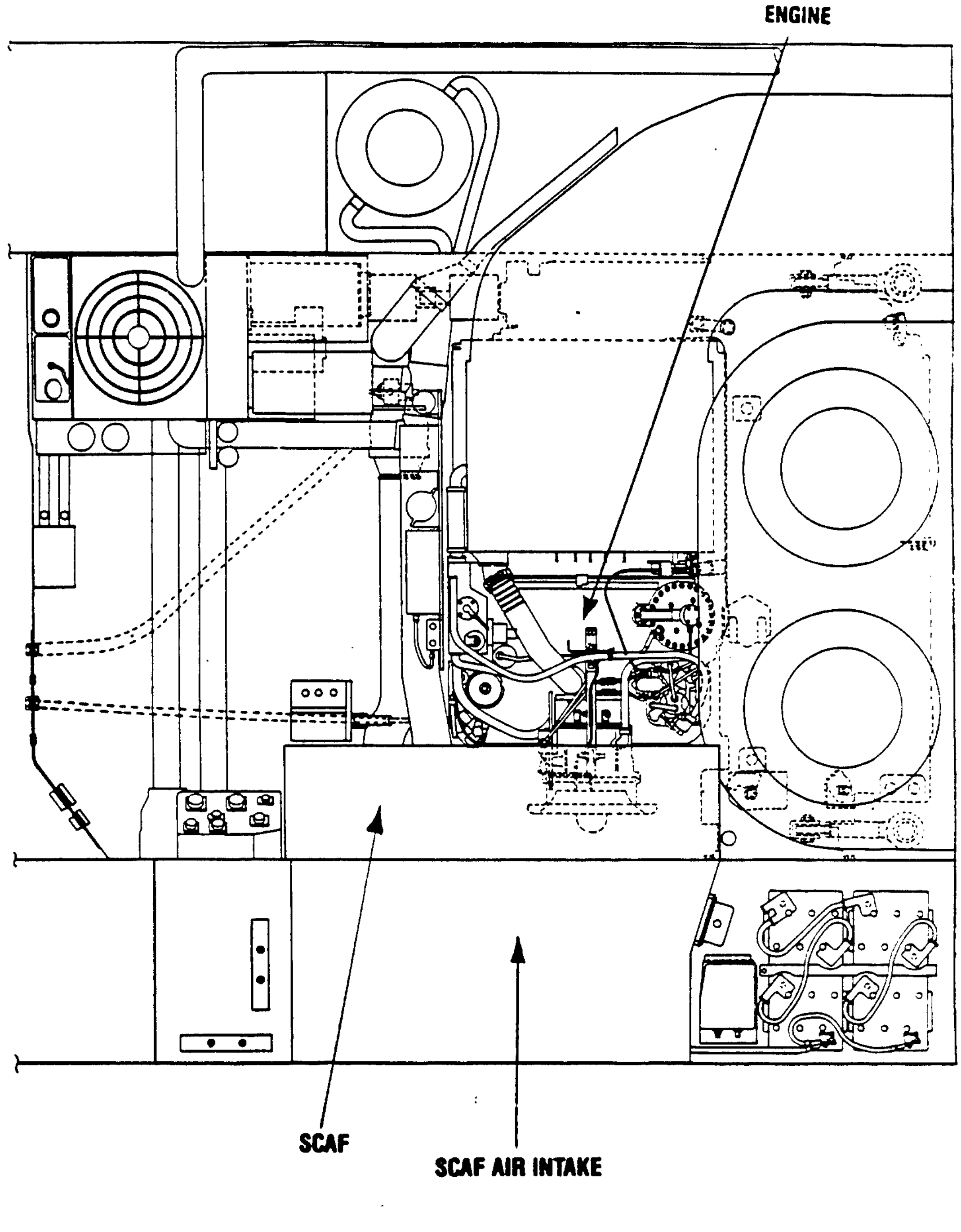


Figure 5-2 Engine (AGT 1500) and Air Induction Installation

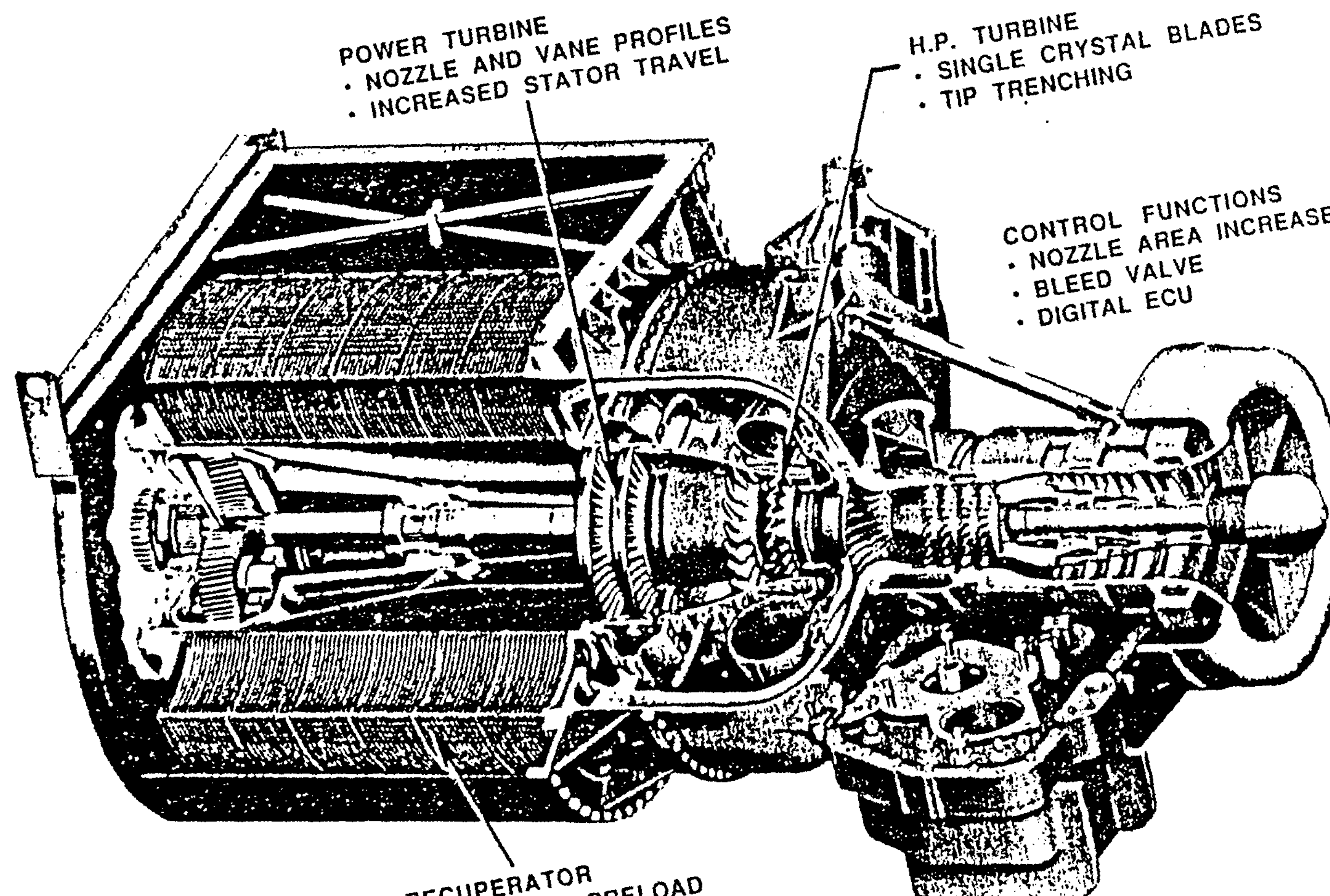


Figure 5-3 Engine Hardware Improvements

- o Fuel Efficient Power Turbine
  - Rotor and nozzle aerodynamic changes to improve part power fuel efficiency
  - Tighter clearances on the variable geometry PT vanes

- o Recuperator
  - Higher preload
  - Hastelloy-S material
  - All laser welded construction

Air induction to the engine is through the left rear sponson. The air will flow through the engine integrated Self Cleaning Air Filter (SCAF) which includes the precleaners and a rotary barrier filter. A pressurized cleaning nozzle forces the barrier filter contaminants into the vacuum ejector nozzle with high pressure air. A scavenge blower purges the ejector nozzle and exhausts the debris to the vehicle rear. The system provides clean filtered air to the main engine, APU, and NBC system.

5.1.2 Transmission and Final Drive. The TMEPS XT1100 hydrokinetic transmission is a modified X1100-3B currently used in the M1A1 vehicle (Figure 5-4). The XT1100 provides superior range coverage through the use of seven forward and three reverse speeds. The transmission retains the X1100 hydrostatic steer unit, parking and service brake system, torque converter, and utilizes a new digital ECU to control range control functions and to communicate with the engine digital ECU. The transmission also incorporates four Power Take Off (PTO) pads to power the accessory drive system, the powerpack cooling system, including a spare alternator drive.

The TMEPS final drives use the same M1A1 mounting but will not be interchangeable with the M1A1 units. The gear ratio is changed from 4.667 (M1A1) to 5.067:1 (TMEPS).

5.1.3 Auxiliary Power Unit (APU) and Accessory Drive. An underarmor APU is used to provide reduced fuel consumption, alternate electrical and NBC power, and reduce main engine run time, (Figure 5.5). Clean air is ducted to the APU from the SCAF system. The APU system consists of a John Deere rotary engine with integrated starter, fuel conditioning system, cooling system, and back air filtration, and is coupled to the vehicle accessory gearbox (VAG) to power the alternator, NBC compressor, SCAF compressor, scavenge blower and hydraulic pump. The APU exhaust is ducted to the rear of the vehicle.

The accessory drive system interfaces with both the constant speed APU and the variable speed automotive transmission PTO. Utilizing an integral continuously variable transmission (CVT), the VAG supplies a constant speed drive for the following accessories:

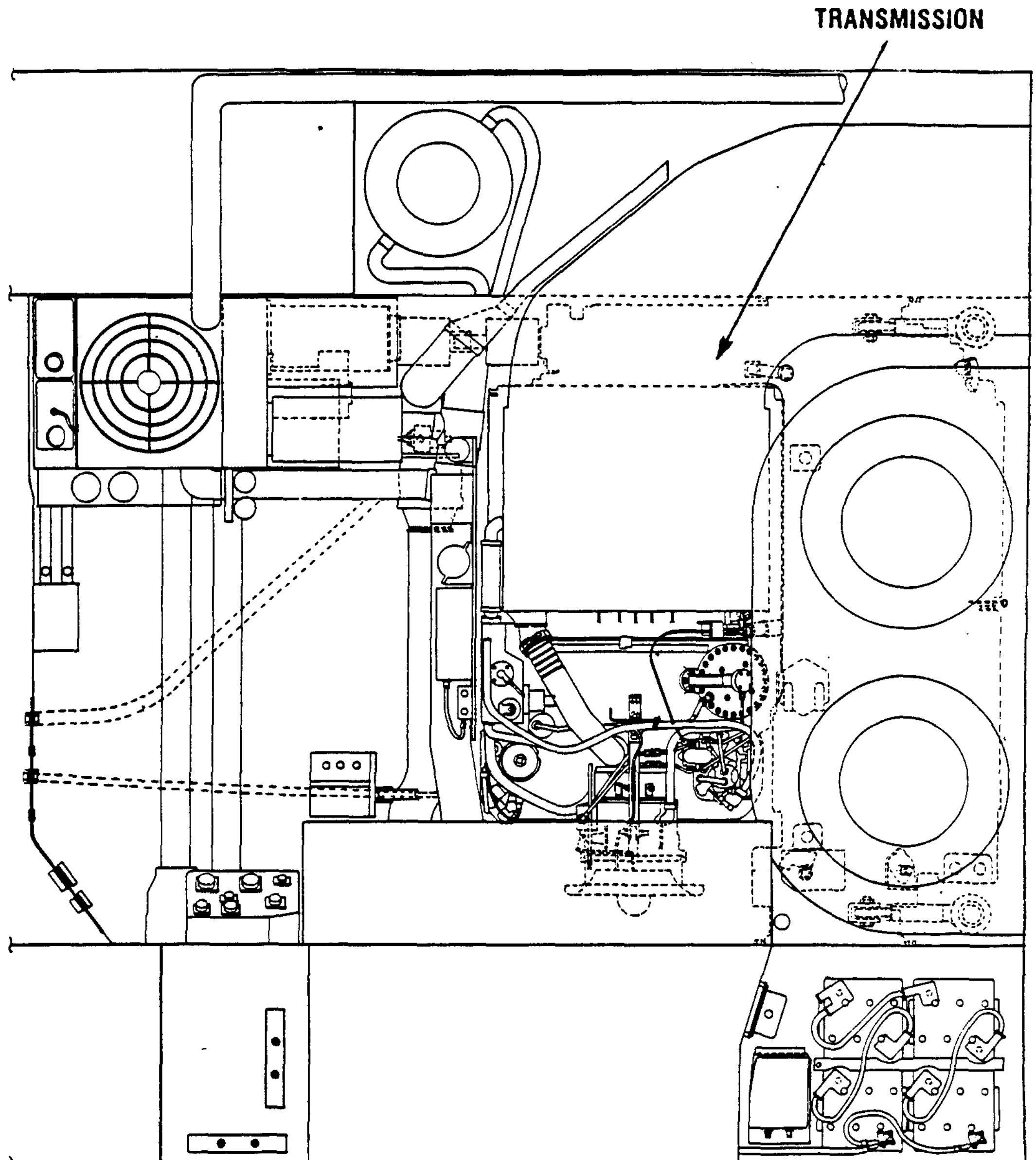


Figure 5-4 Transmission (XT1100) Installation

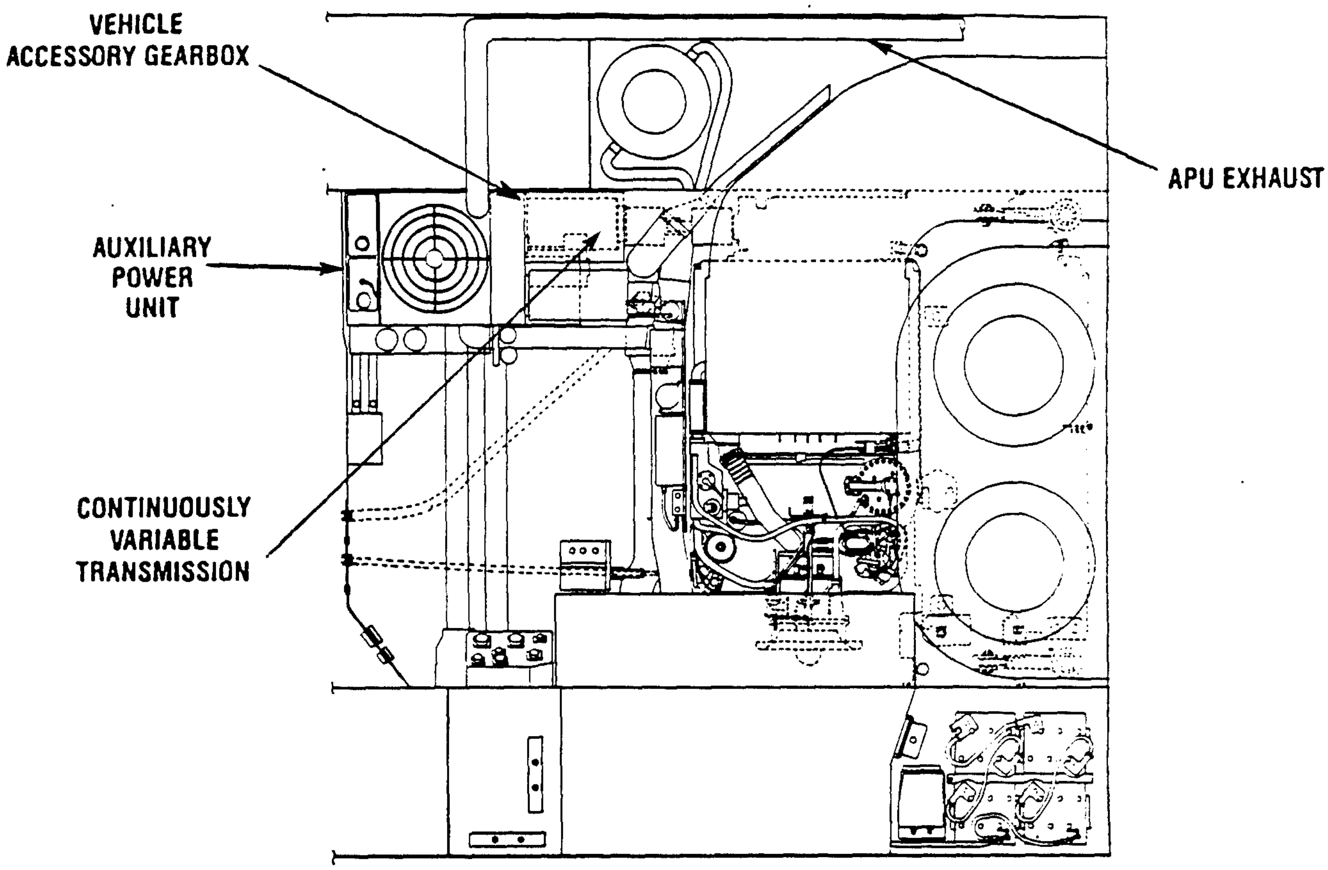


Figure 5-5 Auxiliary Power Unit and Accessory Drive Installation

- o During Main Engine Operation
  - NBC Compressor
  - Alternator
  - SCAF Compressor
  - Scavenge Blower
  - Main Hydraulic Pump

- o During APU Operation
  - NBC Compressor
  - Alternator

5.1.4 Cooling and Exhaust System. A mechanical cooling fan drive system is integrated to the powerpack (Figure 5-6). There are two integrated ring coolers; each contain a fan and a diffuser within the cooler space claim. The fans are individually clutched for independent operation and mounted to the transmission power takeoffs. The coolers are shrouded to control air circulation in the engine compartment.

The exhaust of the APU, main engine and coolers will exit from the vehicle rear similar to M1A1.

5.1.5 Hydraulic System. The current M1A1 hydraulic pump is retained for the hull/turret drive systems, (Figure 5-7). This pump also drives an accessory cooling fan motor during main engine operation.

5.1.6 Fuel System. The vehicle front fuel tanks supply fuel to the engine, APU and smoke generator system, (Figure 5-8). The fuel is pumped directly from both tanks and thereby eliminate a more complex fuel transfer system. The ATR fuel system provides sufficient range for automotive testing only and is not indicative of a production vehicle. A full-up fuel system design is not to be accomplished as a part of the test rig program.

5.1.7 Electrical System. The electrical system interfaces with the engine and transmission, CVT-Accessory Drive Gearbox, SCAF, hydraulics, APU, NBC system, fuel system, and fire suppression system (Figure 5-9). The electrical system is configured around four 6TL 120 amp-hour batteries and a 650 amp, 28 volt DC alternator driven by the APU or 120 main engine. An APU/SCAF control panel to monitor APU and SCAF operation is designed for and installed in the driver's compartment (Figure 5-10). An auxiliary networks box is designed for and installed under the turret basket to power TMEPS peculiar accessories.

5.1.8 Driver's Control System. The driver's controls (throttle, steering, parking, service brakes, and shifting) are essentially unchanged but require different cable routing and connecting configurations.

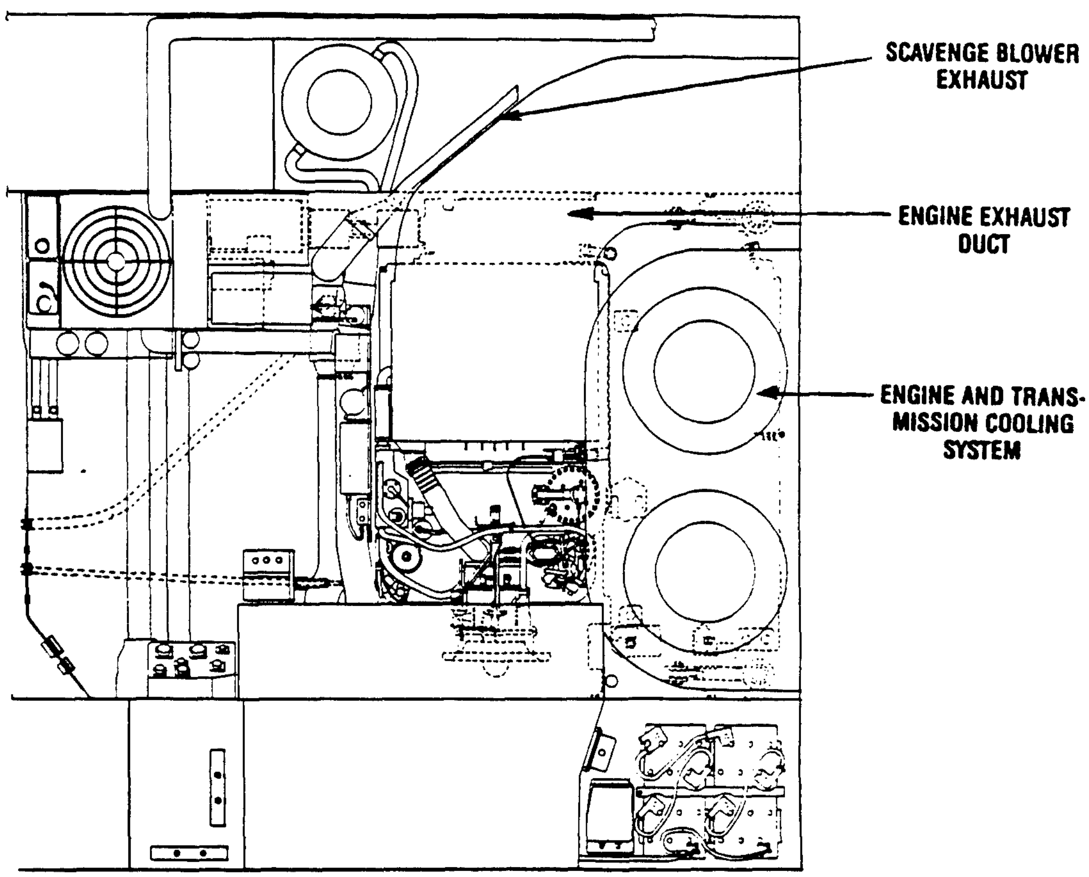


Figure 5-6 Cooling and Exhaust Installation

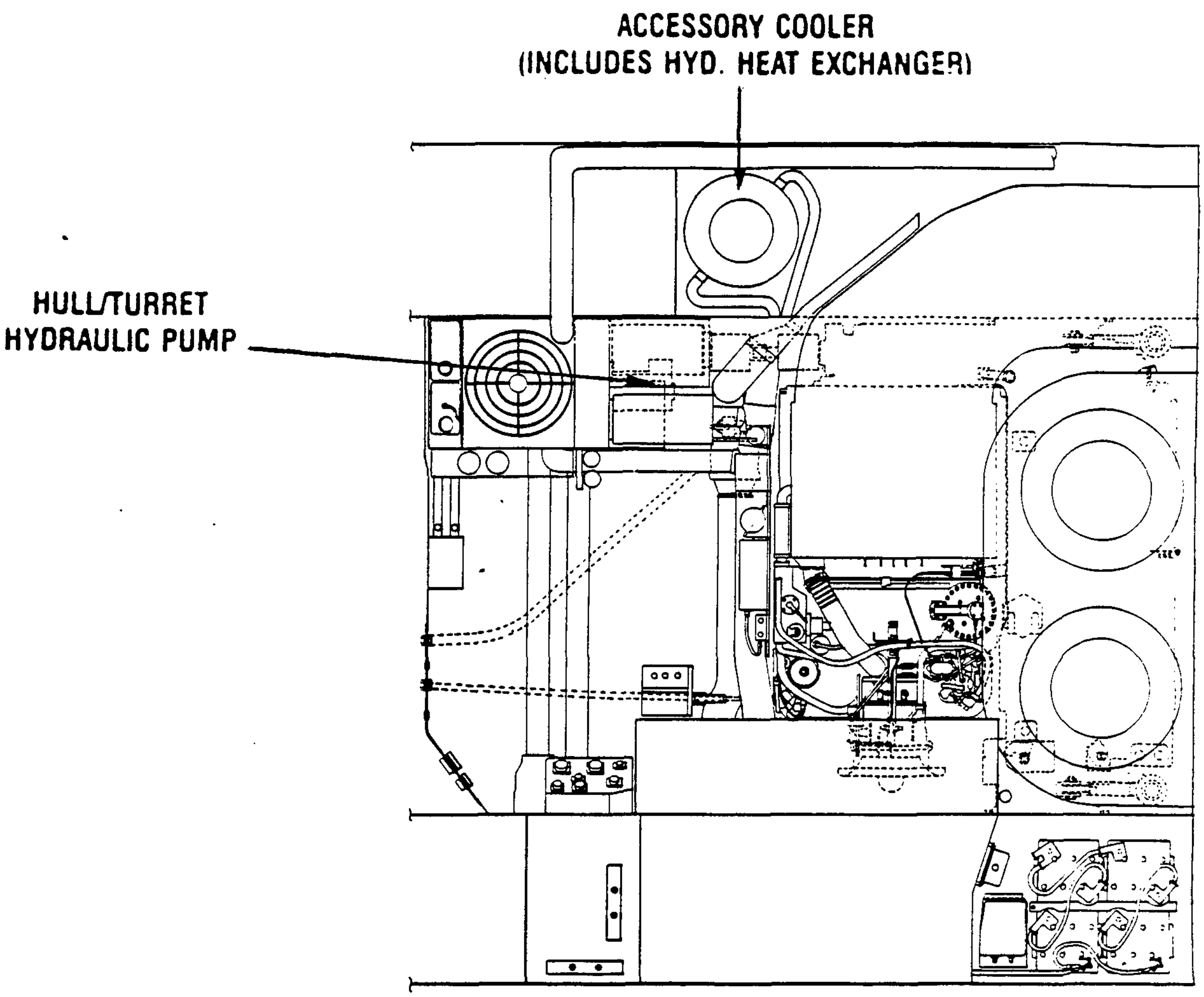


Figure 5-7 Hydraulic System Installation

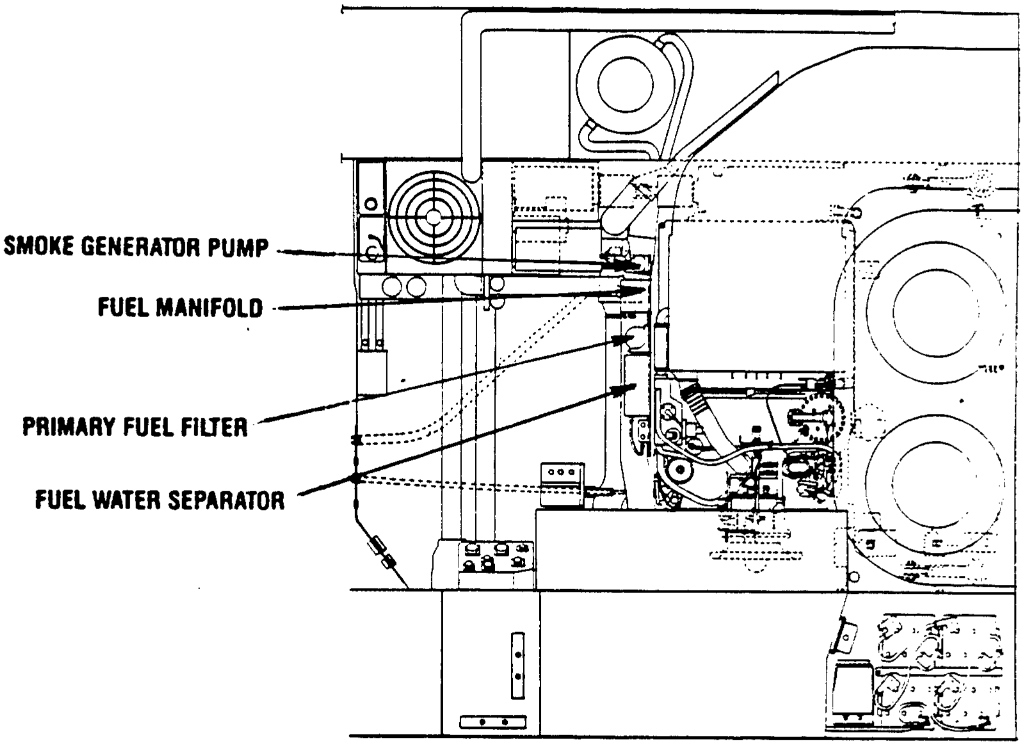


Figure 5-8 Fuel System Installation

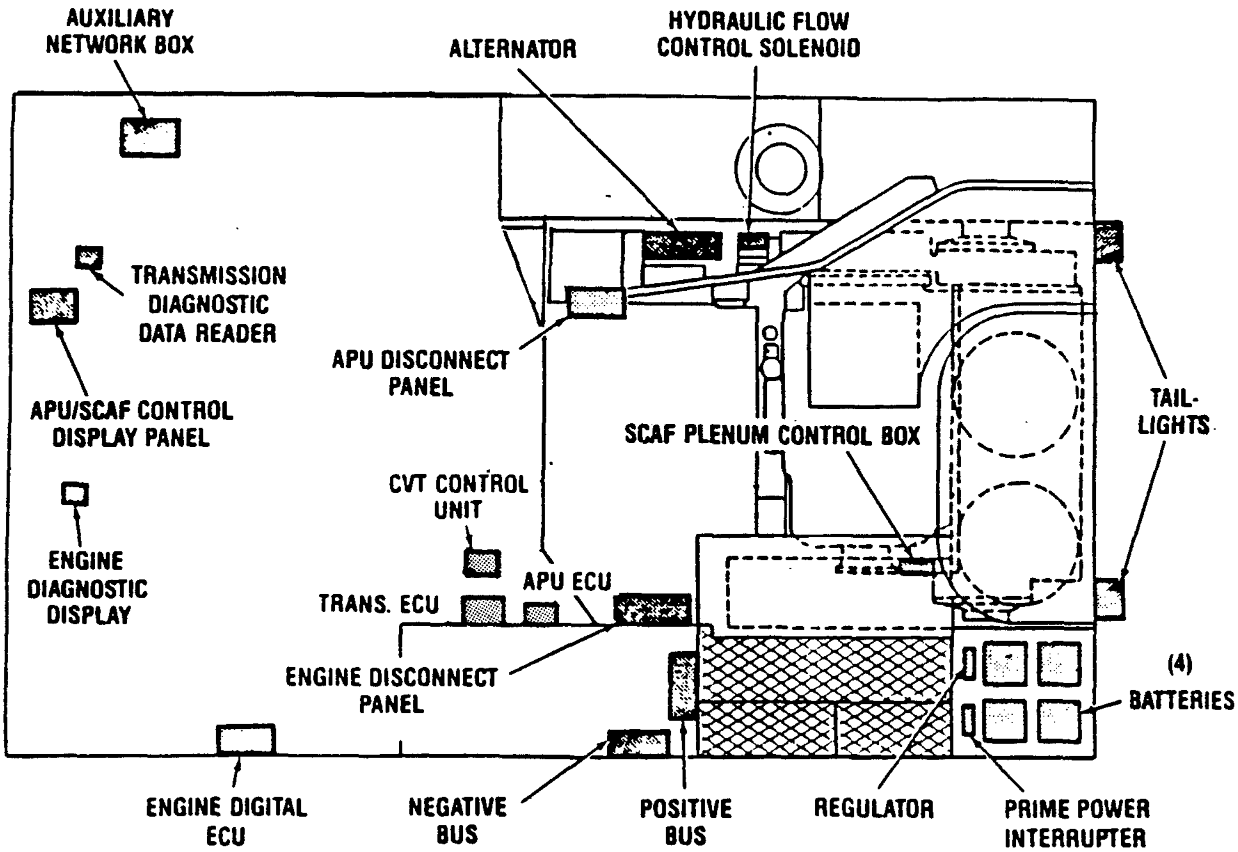


Figure 5-9 Electrical System Installation

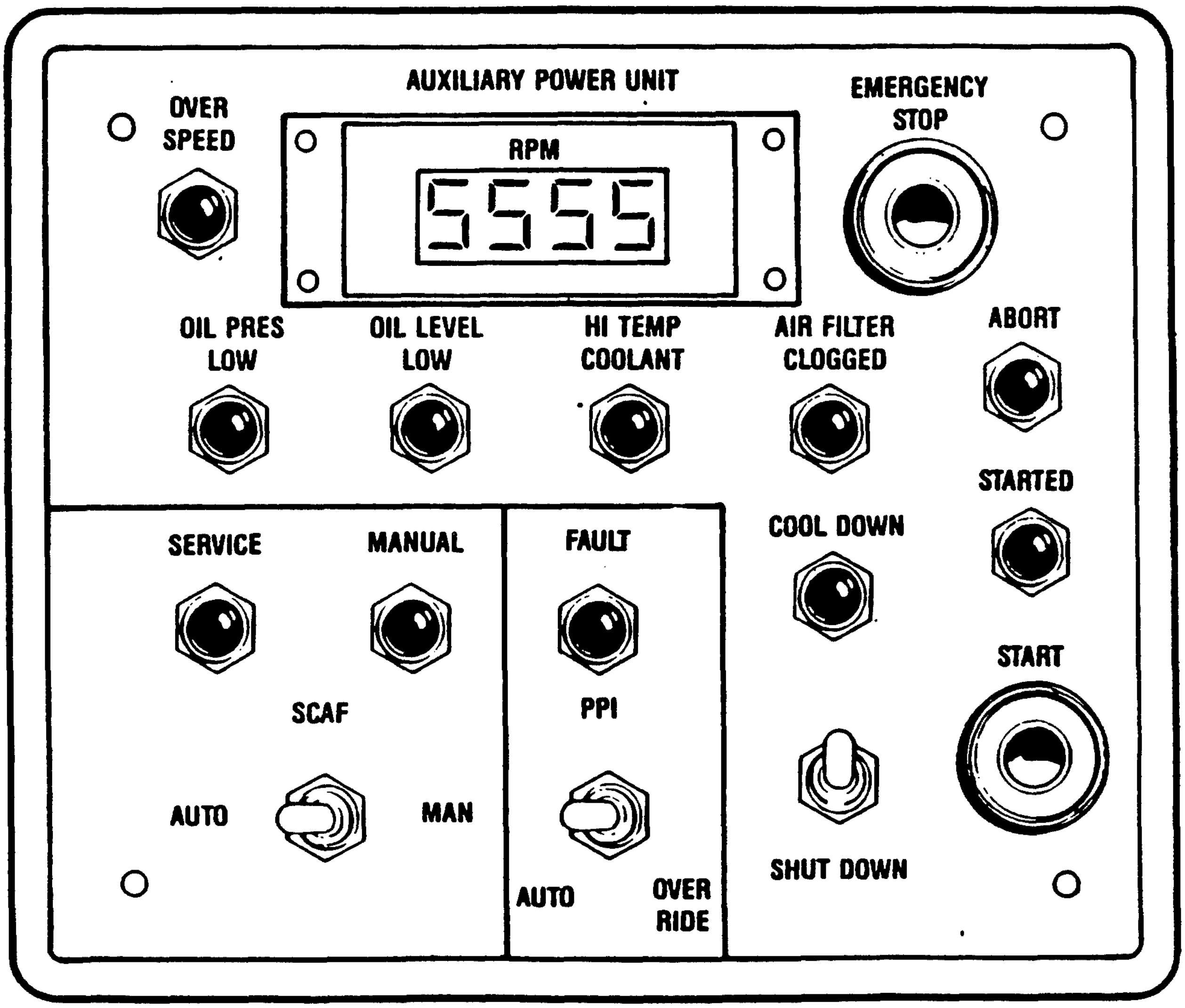


Figure 5-10 APU/SCAF Control Panel

5.1.9 Vehicle Structure. The vehicle rear hull structure is modified to accommodate the transverse powerpack (engine and transmission), exhaust systems, SCAF, access doors, and grilles. Ballistic protection and structural integrity will be maintained equivalent to M1A1. Ballistic protection will not be provided on the ATR vehicle although space claim is provided.

5.1.10 Life Cycle Cost (LCC). The LCC analysis has been conducted using the RCA price models of costing to estimate development, production, operation, and support costs (less overhaul) for the three vehicles (M1A1-86, M1A1-91, and TMEPS).

5.2 Design

The changes to the M1A1 vehicle hull and its propulsion system interfaces, to accommodate the TMEPS propulsion system, are presented and discussed herein. The technical approach, goals, design analysis, tradeoffs, and selected designs are presented for each design system. The systems discussed are:

- o Engine and Air Induction
- o Transmission and Final Drives
- o Auxiliary Power Unit and Accessory Drive
- o Cooling and Exhaust System
- o Hydraulic System
- o Fuel System
- o Electrical System
- o Driver Control System
- o Structure

5.2.1 Engine and Air Induction.

5.2.1.1 Goals. Improvements were demonstrated through use of an Automotive Test Rig (ATR). The engine and air induction system goals were:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
ENGINE		
Powerpack Density Increase	Increased	Same as ATR

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
ENGINE		
Environmental Specifications		
Same as M1A1	Same as M1A1	Same as M1A1
Engine Idle		
Normal Idle-900 RPM TAC Idle-1300 RPM	Normal Idle Same-900 RPM TAC Idle-1300 RPM	Same as ATR
Modular Interchange-ability Maintained	Maintained (Except Accessory Gearbox)	Same as ATR
Starting At Temperature Extremes		
Same as M1A1	Same as M1A1	Same as M1A1
Starting Attitudes		
Same as M1A1	Same as M1A1	Same as M1A1
Fuel Consumption (ref. Section 2.1.3.1)		
10% Weighted Improvement	10% Weighted Improvement Guranteed	15% Weighted Improvement Projected
Powerpack Clearance		
Maintain M1A1 Standards	Exceptions will be identified	Same as ATR
Engine Controls		
Digital ECU w/ Diagnostics	Digital ECU w/ Diagnostics	Same as ATR
Engine Cycle Temperature T_7 not to Exceed M1A1	Maximum not Exceeded	Same as ATR
Powerpack Mounting		
Vertical removal of powerpack	Vertical Removal	Same as ATR
AIR INDUCTION		
Filter Life		
Same as M1A1	10X improvement demonstrated over M1A1	Same as ATR
Filter Efficiency		
Same as M1A1	Same as M1A1	Same as ATR

5.2.1.2 Technical Approach. An improved AGT 1500 turbine engine is the prime mover for the M1-TMEPS vehicle. It is transversely mounted with its axis parallel to the transmission axis, as opposed to the "T" configuration in the M1A1 vehicle Figure 5-11. This transverse mounting provides a more efficient utilization of space by providing a higher density propulsion system.

The SCAF, Figure 5-12, is integrated with the engine and mounted to the bellmouth. As the SCAF barrier filter drum cycles, a cleaning nozzle backwashes the clean side of the barrier filter with high-pressure air into the vacuum ejector nozzle. The cleaning nozzle air is supplied by the SCAF compressor mounted on the vehicle accessory gearbox. The dirt particles pass into a scavenge fan through a duct and out the rear of the vehicle.

The design guidelines for the engine were:

- o Eliminate the NBC engine bleed for increased fuel economy and RAM-D.
- o Retain maximum individual parts commonality with current AGT 1500 engine for minimal logistics impact.
- o Minimize hull structure modifications.

The engine characteristics are equivalent to the M1A1 configuration except for:

- o Removal of the hydraulic pump to the vehicle accessory gearbox
- o Reduction in specific fuel consumption

TMEPS internal hardware changes compared to M1A1-86, Figure 5-13, to improve fuel economy and RAM-D are:

- o Power Turbine - Blade profile change
- o Recuperator (Hastelloy-S and increased preload)
- o High pressure turbine - single crystal blades
- o High pressure turbine - trenched cylinder
- o Digital Electronic Control Unit (ECU)
- o High pressure and low pressure nozzles - minor modifications to flow areas

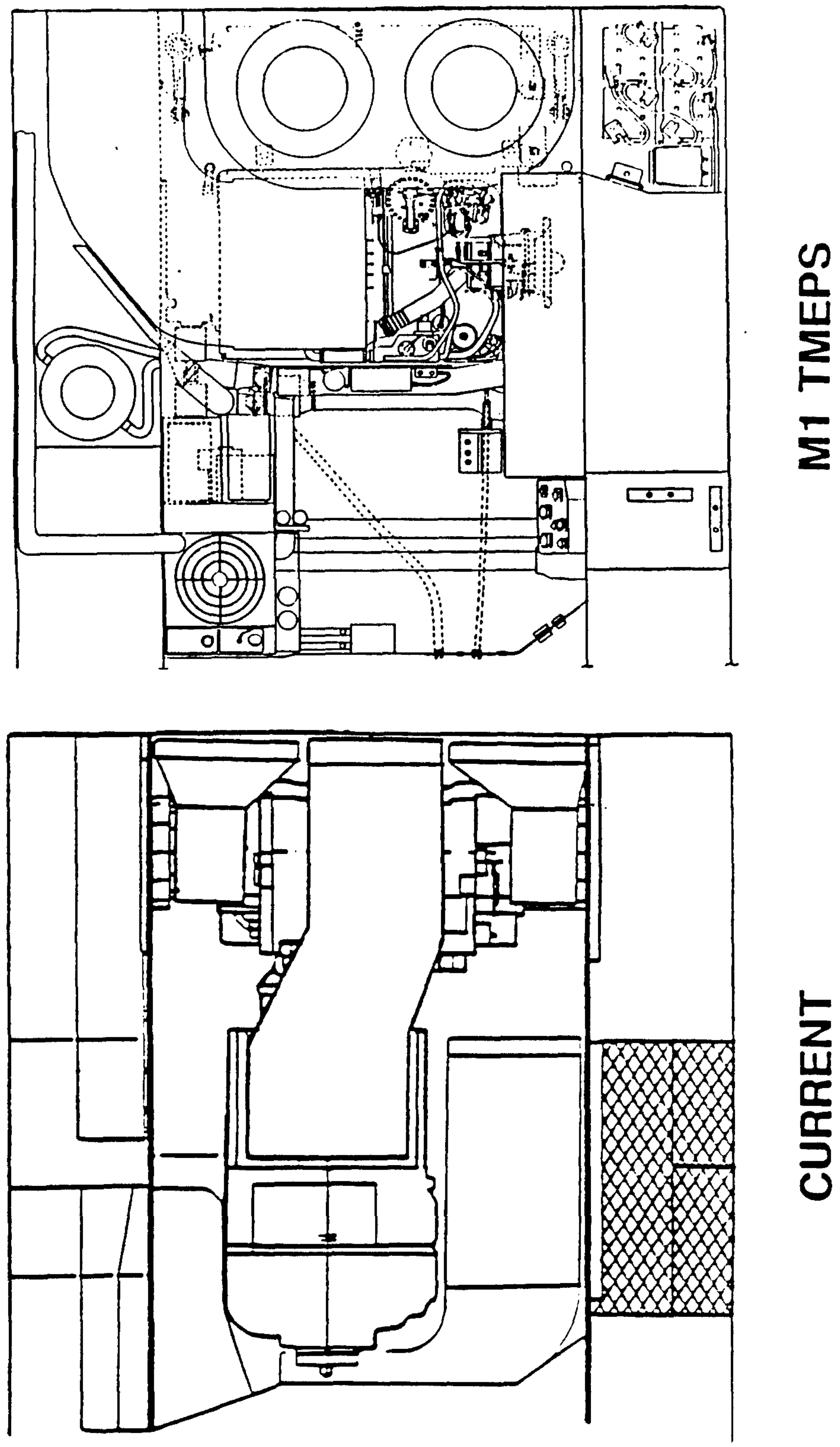


Figure 5-11. M1 Current and TMEPS Propulsion System Installation

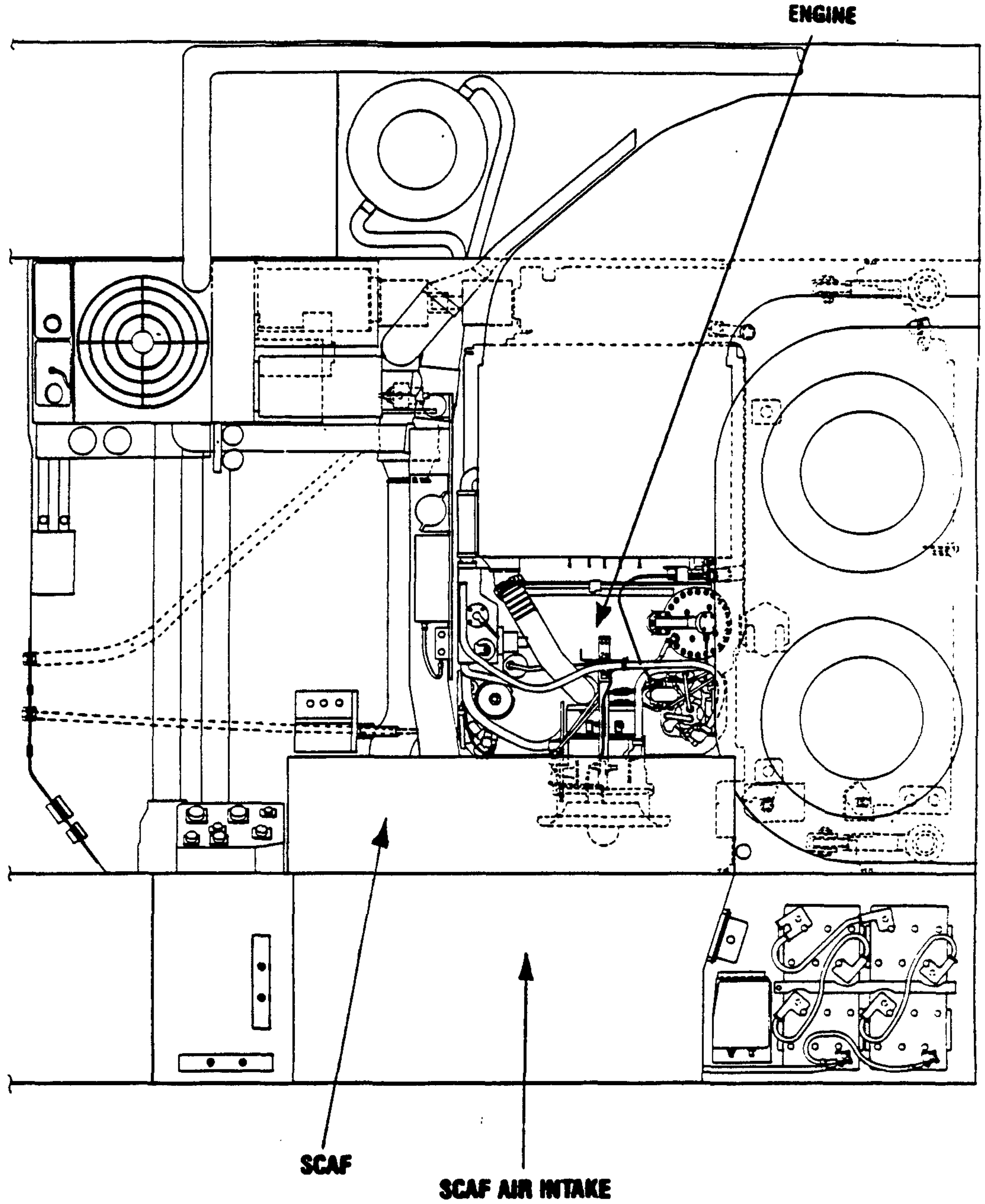


Figure 5-12. SCAF Installation

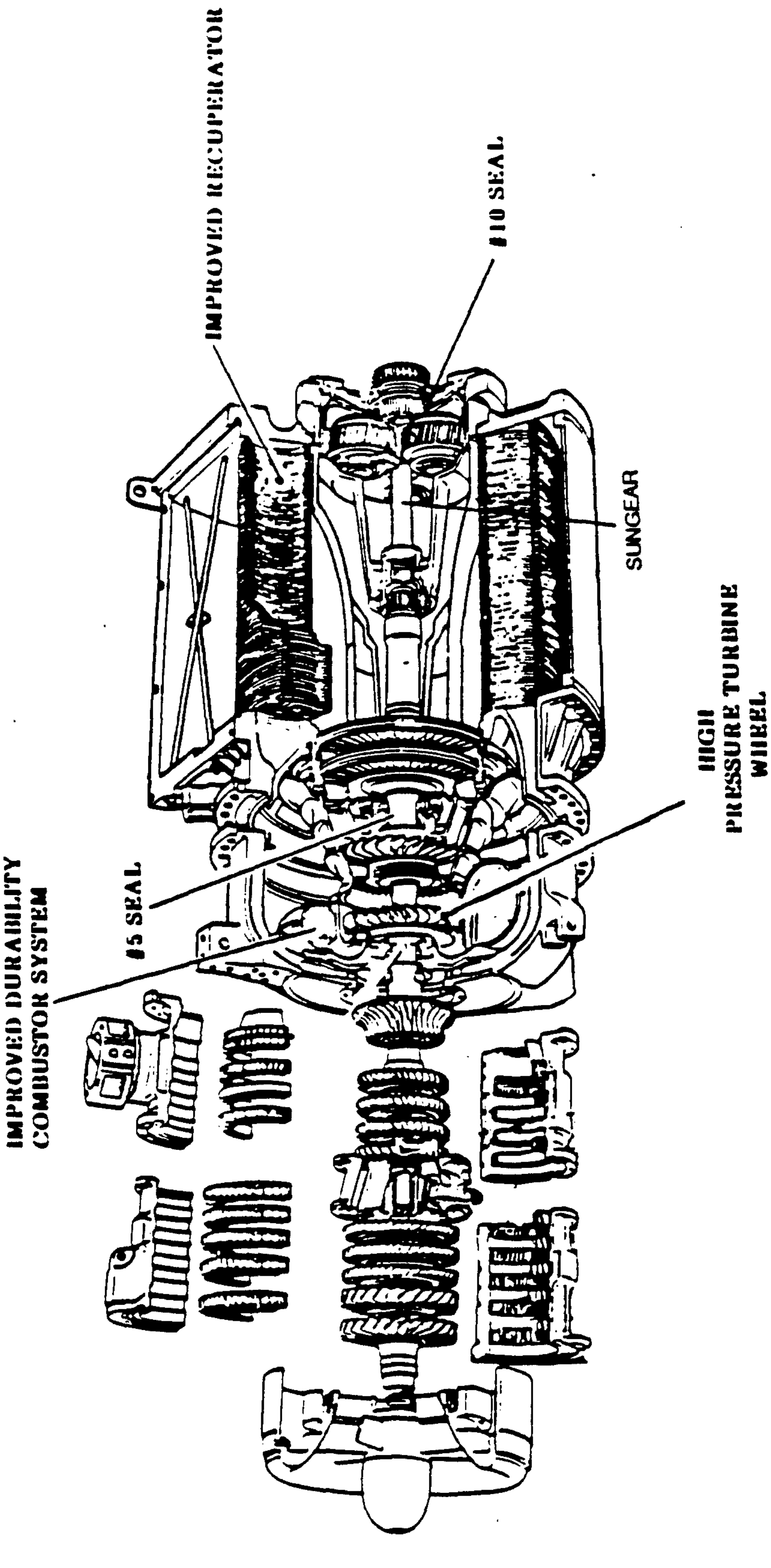


Figure 5-13. Engine Hardware Improvements

- o Polygon drive for accessory gearbox
- o Deep Groove #11 and #13 Conrad bearing races
- o Increased (5%) cooling flow high pressure turbine nozzle
- o Alternate (VASCO) sungear material
- o Improved durability #5 and #10 seals
- o Upgraded fuel handling unit seals
- o Incresed (25 percent) lubricant flow in reduction gearbox

The air induction design guidelines were:

- o Reduce unit space claim and weight by minimizing active filter face area.
- o Reduce operating and support costs by increasing filter service interval by a factor of ten.
- o Reduce air inlet restriction.
- o Provide stationary back-up filter.

5.2.1.3 Design Analysis. The program objective is to demonstrate by cell test a minimum 10 percent weighted fuel savings as compared to current M1A1 product fabrication specification E2180C based on ATR (63 Ton) Peacetime Annual Usage duty cycle with NBC off, corrected and adjusted to 87°F, 500 FT ambient conditions. The engine speeds and loads for duty cycle comparisons shall be the same as in the annual peacetime usage scenario. Those portions of the duty cycle which contain APU operations shall be deleted from the comparison for the M1A1 and TMEPS.

<u>Mission Fuel Consumption Analysis/Testing</u>

The predicted program SFC design criteria improvements relative to the M1A1 Fabrication Specification (engine only - no APU) are:

- o ATR SFC Guarantee (condition-peacetime, 87°F, 500 ft. altitude, weighted average) 10%
- o ATR SFC program goals 12%
- o FSED/production goals 15%

The major component contributors to the 10% peacetime fuel usage reduction (FSED Engine, GVW 65 tons, 87°F, 500 ft. altitude) are:

Component:	Scheduling/ Controls	Recuperator	Power Turbine	Gas Producer
Contribution:	4.3%	2.1%	2.6%	1.0%

Digital Electronic Control Unit (DECU)

The DECU incorporates the operating schedules for the improved fuel economy TMEPS engine. These schedules included power turbine stator open and closed positions, temperature limits, interstage bleed, inlet guide vane (IGV) position, and fuel flow control. These scheduled, in addition to hardware improvements, provide improved fuel economy. The digital ECU also contains diagnostic software sufficient to replace the STE-M1 hardware relating to the engine. Diagnostic information will be displayed with both a window on the side of the ECU and a hand held set-com located in the driver's station. Communication with the transmission ECU will be attained through a data bus.

Recuperator Performance Analysis and Module Tests

The recuperator incorporates a new core design, with the following improvements:

- o Material change to Hastelloy-S from current IN-625
    - Provides 10 percent lower expansion coefficient
    - Improves predicted life for axial cracking mode by a factor of 2X.
- o Preload increased from 15000 to 25000 lbs.
- o Improves effectiveness by 3 percent
- o Provides 20 percent of total peacetime fuel usage reduction
- o Additional improvements resulting from ongoing improvement programs will be factored into present production as validated.
    - Convolutions over triangles
    - ID football bumpers
    - Stress relief
    - Sunburst plate modifications

The recuperator test results are as follows:

Factor	High Density Design Point	High Density Actual	FEP#1	FEB#2
System Effectiveness at 1200 SHP	70.4	63.5	69.8	69.2
Gas Side Pressure Drop - Percent	-2	9.7	11.5	11.5
Preload - (Kips)	33	30	25	18

NOTE: Fuel Economy Program (FEP) #1 is similar to TMEPS configuration with the exception that FEP #1 used IN 625 as opposed to Hastelloy-S material.

Recuperator

The recuperator contributes about 21% of the total engine peacetime mission weighted fuel savings relative to the M1A1 Engine Fabrication Specification. The recuperator influence coeficients are:

- o 1% increase in effectiveness lowers mission fuel consumption by 0.7%.
- o 2% decrease in gas side pressure drop lowers mission fuel consumption by 0.5%.

The long range (1991 production) improvement goals are:

- o Performance - 2% mission fuel consumption improvement due to:
  - o Effectiveness
  - o Pressure drop
- o Full interchangeability with existing core

Power Turbine

The power turbine used blade angles that produce high efficiencies in the low power range where specific fuel consumption improvements are more significant. Power turbine stator first stage nozzle guide vanes have extended operating range to provide a better engine match.

The design criteria for part power efficiency improvement were:

- Raise peak efficiency by one percent over M1A1 production.

- Move the peak efficiency operating point to a 13% lower flow function.

- Maintain the 1500 SHP capability as a minimum.

The improvements obtained through rig tests were:

- Peak efficiency operating point was demonstrated at 12 percent lower flow function (preliminary)

- Peak power capability was maintained in conjunction with other components

<u>Gas Producer</u>

The design objectives were:

- Increase low power surge margin of LP and HP compressors by 2.8 and 4 percent, respectively, to compensate for power turbine and bleed closure at idle speed.

- Increase HP turbine flow function by 4 percent

- Decrese LP turbine flow function by 2 percent

- Maintain component efficiencies

The configuration modifications made were:

- HP and LP housing tip treatment at the first two stages

- HP turbine single crystal blades with reduced cooling flow

- HP rotor and nozzle geometric flow area increased by 4 percent

- HP turbine cylinder modified to incorporate trenching

- LP turbine nozzle geometric flow area reduced by 2 percent.

The gas producer components rig tested were:

- HP and LP compressor (baseline and TMEPS)

- HP and LP turbine nozzle (baseline and TMEPS)

- Trenched cylinder

The results of the tests were:

- o HP Compressor Tip Treatment

  - A 4 percent increase in surge pressure ratio was noted at speeds of less than 85 percent. This is not significant.

- o HP Manifold Diffuser and Idle Bleed Closure - no increase in low speed surge margin and a seven percent increase at high speeds with efficiency penalty.

- o LP Compressor Tip Treatment - no noticeable increase in surge margin noted.

- o HP and LP Turbine Geometry and Cylinder Trenching - predicted flow function adjustments achieved without efficiency penalty.

The selected approaches were:

- o Incorporate trenched cylinder

- o Tip treatment and manifold diffuser were not incorporated for ATR

- o Tip treatment for the compressor section was not used. ATR used on production compressor.

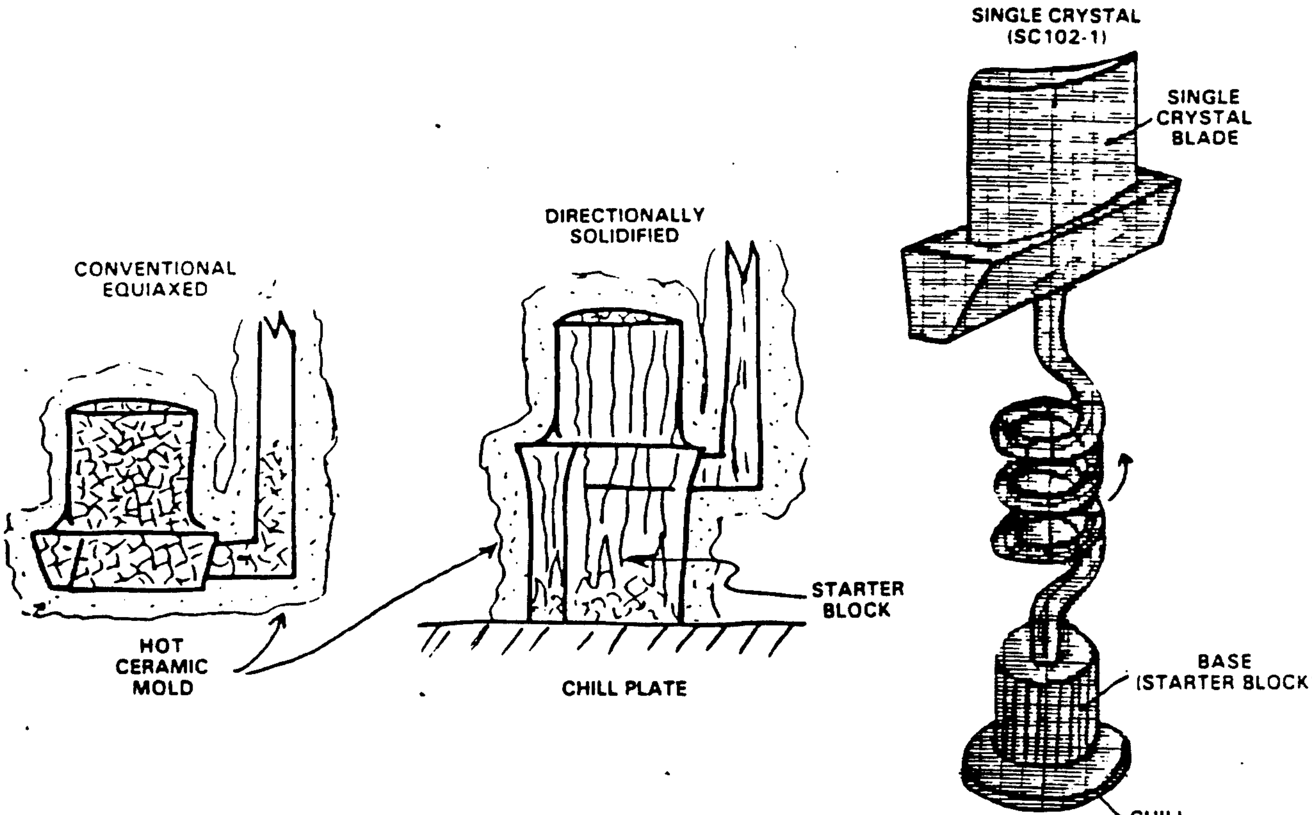
<u>Engine Heat Rejection Analysis</u>

Engine heat transfer into the transmission transfer case was reviewed to verify that the strength of the transfer case was not adversely affected. An analysis of field data was conducted and showed that the heat transfer into the transfer case does not result in temperatures exceeding desired limits.

Other Engine Hardware Changes

<u>Single Crystal Reduced Cooling HP Turbine Blades</u>

The single crystal blade, developed under RAM-D II growth program provides higher strength than the conventional equiaxed or directionally solidified grain structure (Figure 5-14). TMEPS used this design because cooling flow was reduced from 3.4 to 2.0 percent (increases metal temperature 100°F), which contributes approximately 10 percent of the overall engine fuel consumption reduction. The relative blade stress rupture life comparison is:



Schematic of Casting Processes

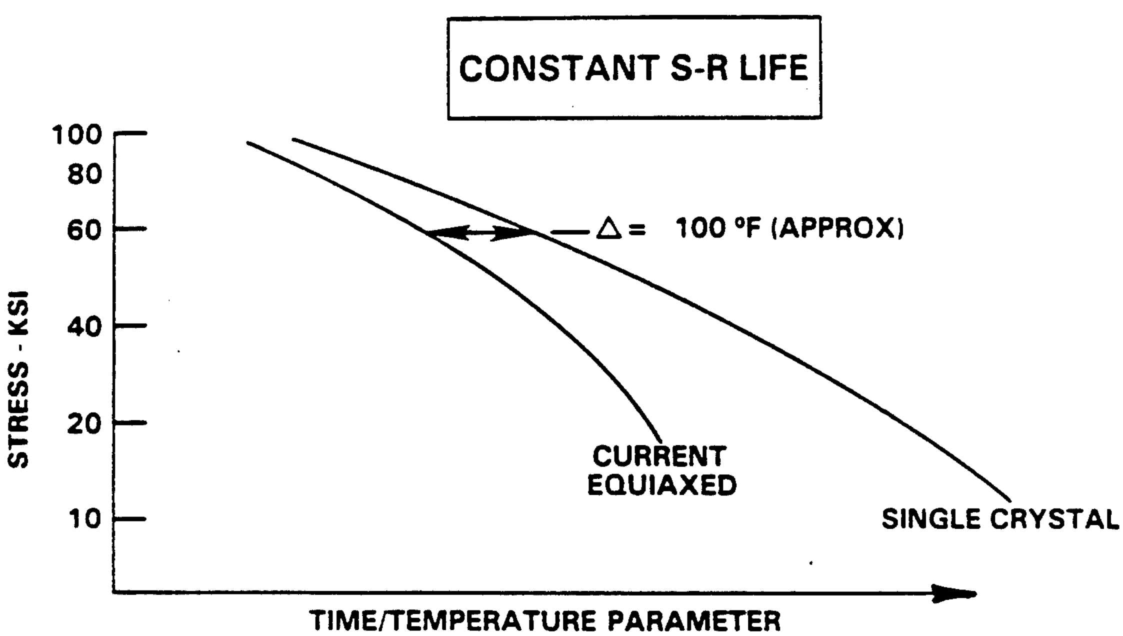


Figure 5-14. Casting Processes and Benefits of Single Crystal Blade

Blade	Cooling Flow	Relative Stress Rupture Life
Equiax Production	Base	Base
Equiax Production	Reduce by 1.4%	Reduce by 50%
Single Crystal	Reduce by 1.4%	Increase by 5X

Polygon Drive System Accessory Gearbox

The splined production configuration can experience difficulties due to the large number of close fitting parts, the potential for accumulated unbalance, and requirement for slip fits during operation.

The polygon system assures improved RAM-D in that the preload is maintained on the position 11 and 12 bearings by substituting a three lobe polygon drive for the involute spline. This eliminates the pilot bushings of the production configuration and assures free movement between the bevel drive shaft and the spline coupling. The design was extensively tested as a part of the RAM-D program and performed well.

Deep-Groove, Position 11 and 13 Conrad Bearing Races

The present bearings are an angular contact ball type with the inner race counterbored so as to produce a cusp (Figure 5-15). Fatigue failures have occurred due to ball contact with the cusp, as well as inadvertent installation in the reverse position.

A deep groove Conrad type ball bearing eliminates the cusp, improves RAM-D, and reduces system costs. The Conrad bearings are interchangeable with production bearings.

Increased (5 percent) Cooling Airflow High Pressure Turbine Nozzle

Nozzle deterioration and circumferential cracking have caused performance degradation. The outer shroud design life limits the durability of existing nozzle configurations. Propagation of the circumferential cracks can cause severe mechanical damage to the engine.

The RAM-D 5 percent cooling airflow nozzle was revised to increse the amount of vane cooling air from approximately 3.2 to 4.8 percent, thus reducing the temperature by 200°F during transients and 120°F during steady state operation (Figure 5-16).

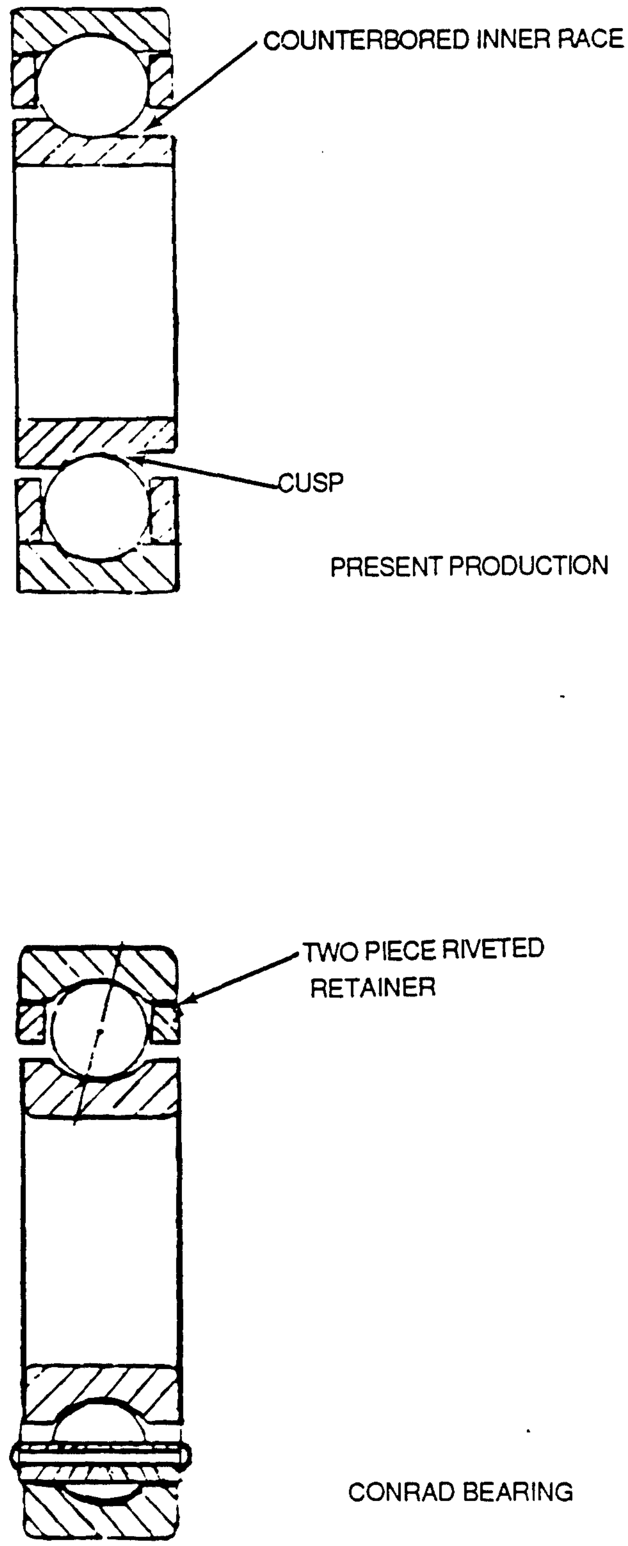
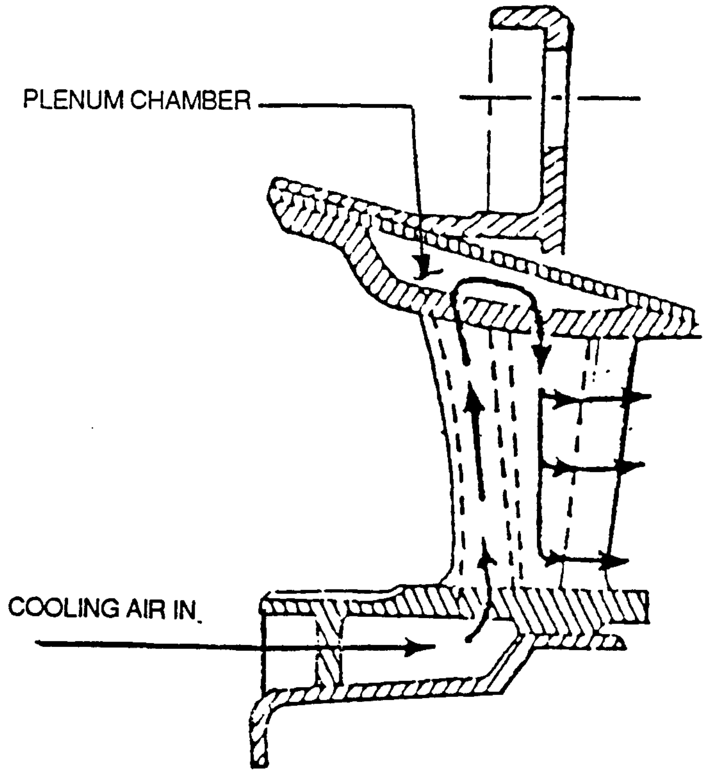


Figure 5-15. Comparison of Present Production Bearing and Improved RAM-D Conrad Bearing Configurations



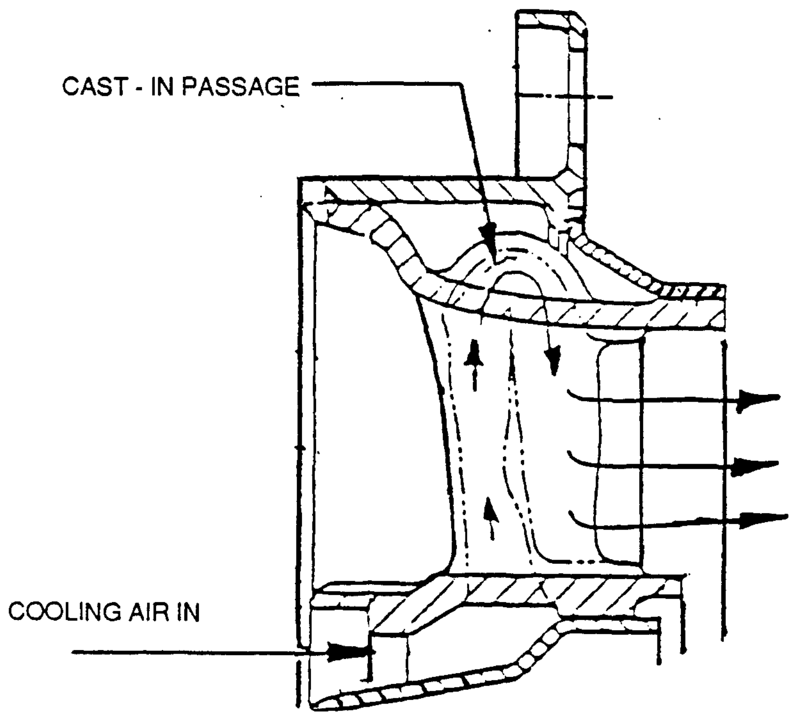


Figure 5-16. Five Percent (5%) and Production HP Nozzle

The material for the improved RAM-D nozzle is C-101 instead of IN718. The nozzle is fully interchangeable with the current production hardware.

Alternate (VASCO) Sungear Material

The present production sungear (AMS6265 material), (Figure 5-17) is susceptible to frosting, pitting, and spalling of the gear teeth. Tests indicated the source of distress as high frequency alternating tooth stresses caused by gear meshing or induced cavitations of the lube in the gear mesh.

The VASCO material is a high hot hardness steel with increased compressive strength (12%) and increased scoring resistance. The configuration is interchangeable with M1A1 production hardware.

Improved Durability #5 and #10 Seal (Figure 5-18)

Position 5 seal failures cause oil leakage resulting in increased oil consumption and visible smoke in the engine exhaust. Seal installation and breakage problems were eliminated by incorporation of a control gap seal and redesigned seal runner.

Position 10 seal, (Figure 5-19), was redesigned to eliminate the oil leak path between the seal housing and retaining plate. The seal is made part of the retaining plate giving the seal increased rigidity. A wave spring on the rear side of the seal was incorporated to hold the seal against the runner.

Increased (25%) Lubricated Flow in Reduction Gearbox

The increased capacity oil pump, with 25 percent higher flow capability than the M1A1 pump, provides increased lubrication flow to the gear mesh, reducing temperatures and tooth distress. The pump incorporates additional durability improvements such as a self priming capability, increased strength coupling and lubricant impregnated bearings. It is interchangeable with the standard production engine.

Air Induction

The air induction system receives air through the left rear sponson ballistic grille. Air flows through the grilles into an engine mounted plenum which contains the precleaners and a rotary barrier filter. The grille incorporates foreign object damage (FOD) screens.

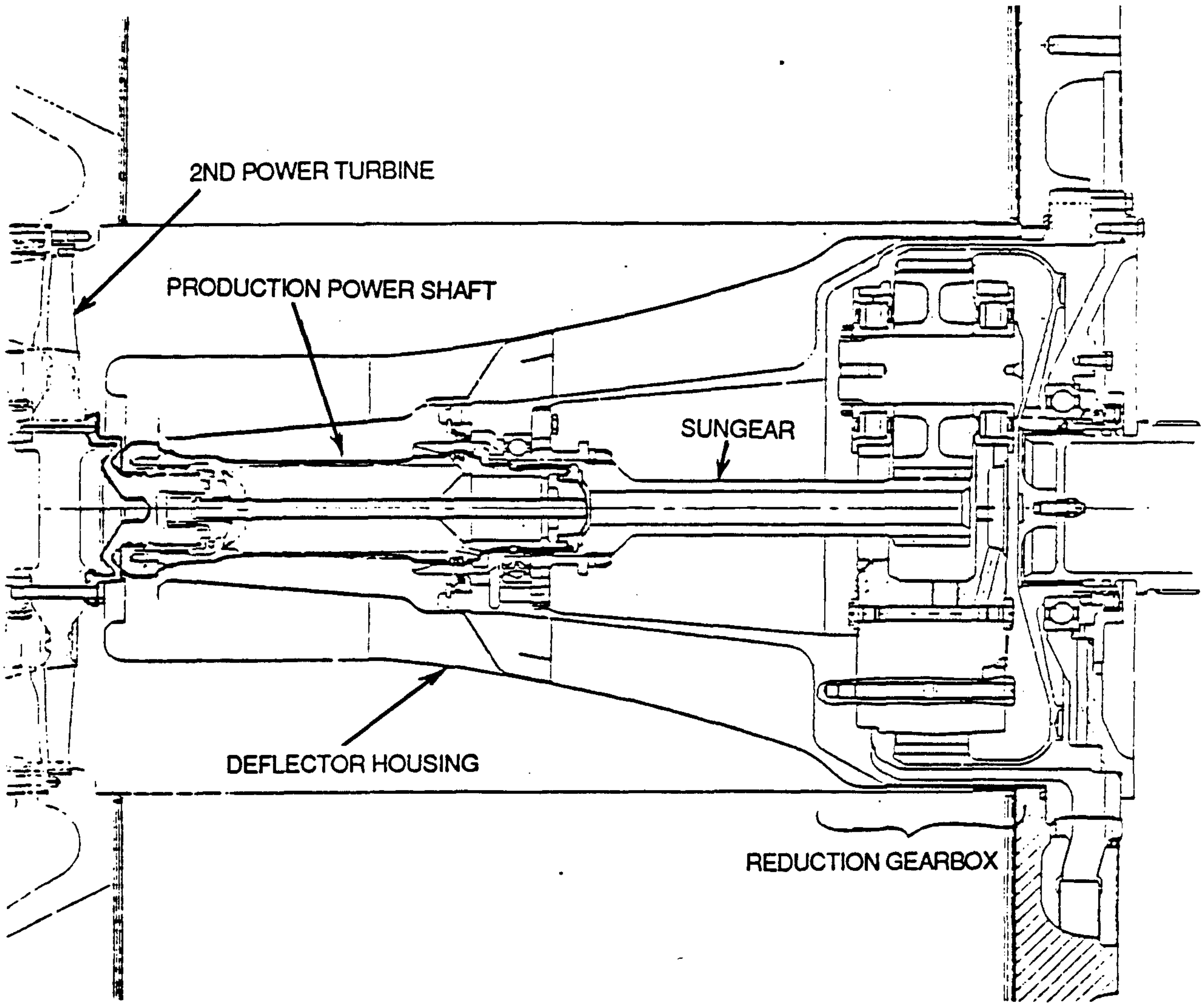
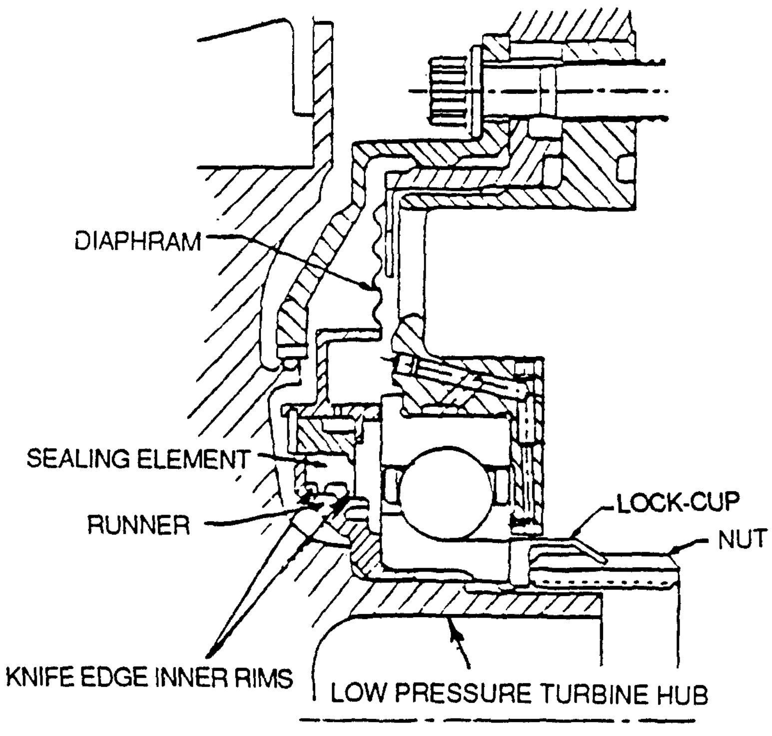
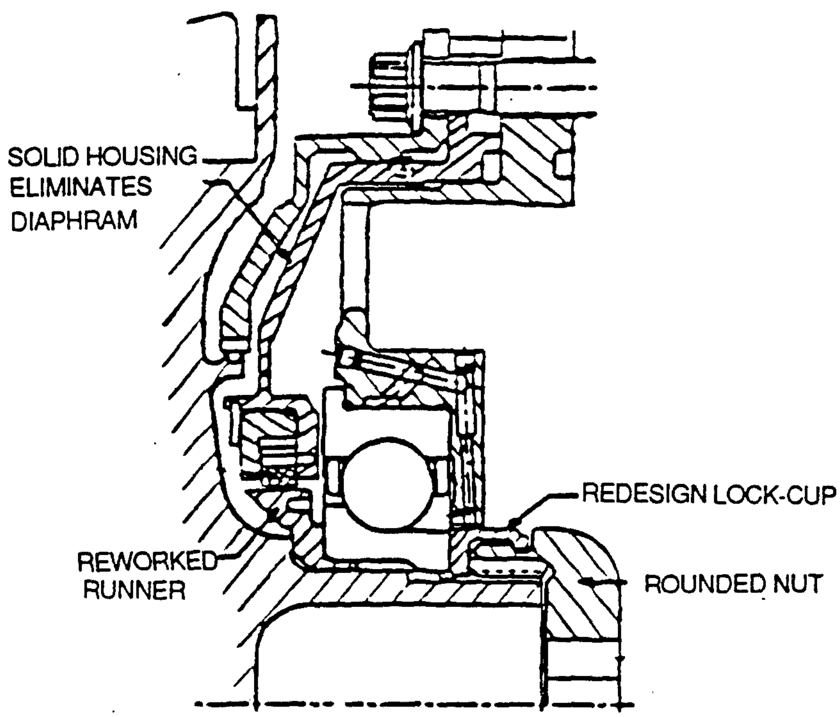


Figure 5-17. Sungear



PRODUCTION POSITION 5 SEAL



RAM-D POSITION 5 SEAL DESIGN

Figure 5-18. RAM-D Position 5 Seal Design

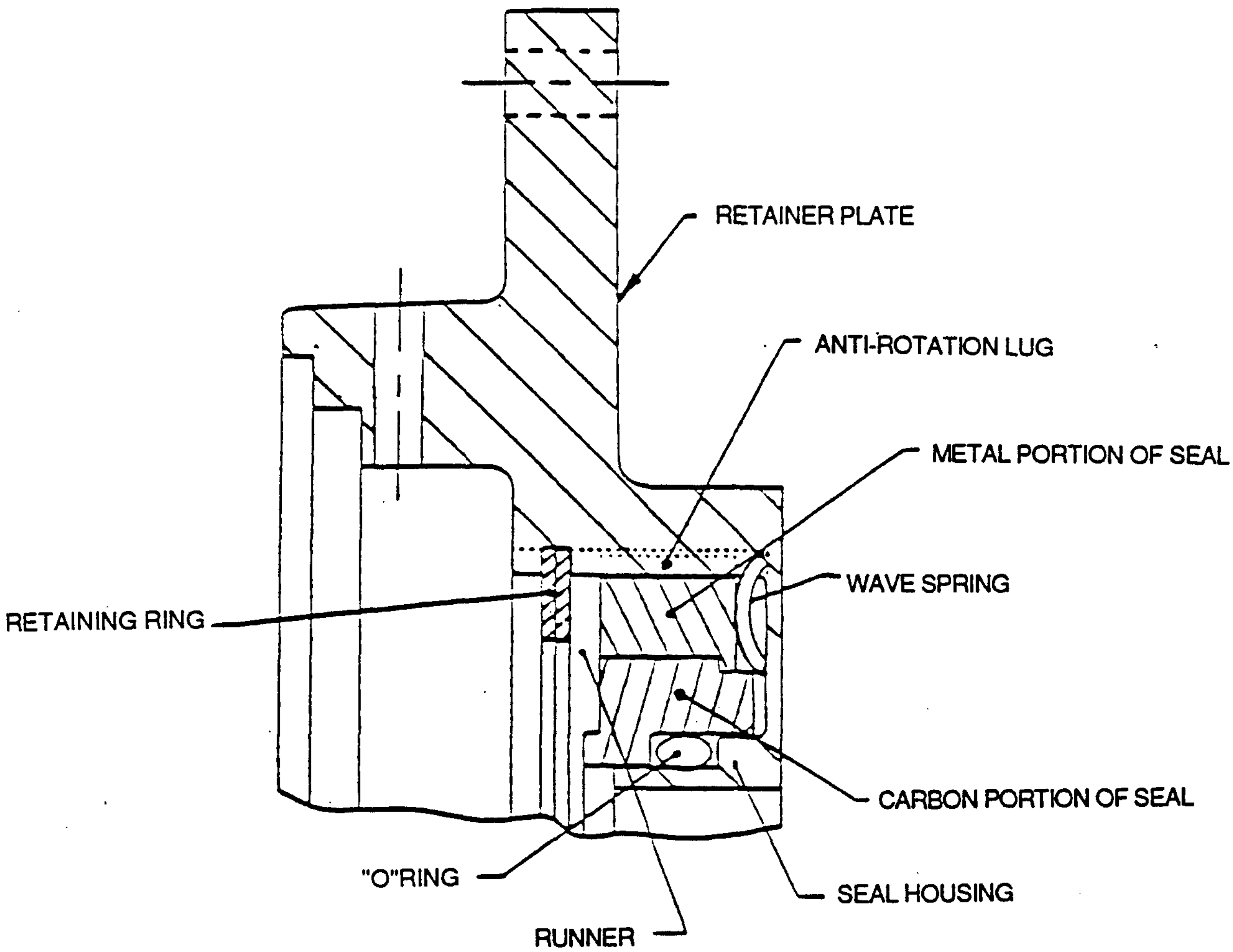


Figure 5-19. RAM-D Position 10 Oil Seal

Precleaner Configuration

The mounting of the precleaner was evaluated using several options:

- o Integrated engine mounted
  - Wraparound precleaner
  - Top mounted vertical precleaner
- o Sponson hull mounted precleaner with engine mounted barrier filter

In analyzing the engine integrated precleaner, a comparison of the wraparound and top mounted configuration resulted in the following:

- o Wraparound
  - Reduced volume
  - Increased service complexity
  - Interferes with 7 speed transmission
- o Top Mounted
  - Allows more compact package
  - Provides large vortex tubes
  - Reduced pressure drop
  - Ease of servicing
  - Completely under armor
  - Eliminates critical interface seal between barrier and precleaner
  - Removable with engine
  - Complete unit for "Ground Hop" operation

It was concluded that the integrated top mounted vertical precleaner was the best selection.

Sponson/Hull Mount - A sponson/hull mount stationary filter study was also conducted with the following criteria:

- Fit the same envelope as the rotating SCAF with a stationary filter
- Improve life, comparable to rotating unit goals

The conclusions drawn from analysis and testing were:

- o The pressure drop across the filters was 34 percent higher than the design goal of 19 inches of water at 11 lb/sec airflow.

- The distortion indices were not acceptable.
- Extensive redesign would be required to relocate the precleaner from the sponson to the engine compartment.
- Donaldson SCAF was selected over the stationary non-SCAF filter as a better approach.

Scavenge Flow Analysis

A precleaner tube analysis was performed to determine the size and estimated scavenge flow performance.

The precleaner tube analysis results were as follows:

Description	SMALL TUBE	LARGE TUBE
Tube size (diam x length)	0.75" x 2.375"	1.5" x 4.37"
Number of Tubes (in single panel)	1232	293
Flow rate/tube (SCFM) at full power	7.5 - 8	31.67
Air velocity (Ft./Min.) at full power	2526.1	2580.7
Pressure drop (inches of water)	3.5 to 4	6.2

In comparing the large and small tube scavenge airflow performance (reference Figure 5-12), the large tube was selected.

Barrier Filter Configuration

The SCAF barrier filter pleat configuration was studied to maximize its efficiency and minimize the pressure loss. A rig test was conducted by varying the pleat density from 4.5 to 7.5 pleats per inch and determining the pressure drop at various air velocities.

An optimum of 6 pleats per inch at 20 feet per minute air velocity was selected. This will provide 4.2 inches of water loss through the media and 200 hour life at zero visibility dust condition.

The total SCAF filter system rig tests with a full scale element were performed to define the pressure drop. With the optimum pleat spacing and vehicle configuration inlet, the total system loss was 15.6 inches of water as compared to 19.5 inches (maximum) specified per the M1A1 System Specification.

Detail Design Analyses Testing

- Seal Life and Drag Torque Analysis

The barrier filter to engine inlet were evaluated. An elastomeric lip seal and a ferrofluidic seal were tested using a scaled down model in a 200 hour life test.

The test results were as follows:

- Lip seal
  - Pressure capability verified (160-200 inches of water)
  - Demonstrated 200 hour life, with no degradation
  - Acceptable drag
- Ferrofluidic Seal
  - Pressure capability verified (160 - 200 inches of water)
  - Demonstrated 200 hour life; some seal distress noted
  - Low drag
  - Seal integrity maintained during frequent shutdown/start-up cycles

The elastomeric lip seal was selected over the ferrofluidic seal. A back-up (alternate) teflon lip seal with graphite impregnated skirt was also tested. No measurable leakage was noted as well as no reduction in mechanical integrity.

5.2.1.4 Tradeoffs. Trade studies were conducted on the engine and air filtration as follows:

- ENGINE
  - Increased recuperator preload design vs. high density design
  - Maintain current AGT 1500 engine maximum cycle temperatures vs. increased temperatures.
  - Eliminate all engine bleed requirements vs. engine bleed for air filter cleaning only.
- AIR FILTRATION UNIT

  Barrier Filter Options

- Surface loading vs. depth loading media.

Detail Design Tradeoffs

- Integral mount with existing inlet vs. modified engine inlet.
- Continuous clean vs. pulse jet.
- Electric motor driven vs. hydraulic.
- Independent air supply for cleaning vs. engine bleed.
- 3 barrier elements vs. 5.

5.2.1.5 Selected Design. The selected design for the engine and air induction were as follows:

- o ENGINE

  - 90% parts commonality with AGT 1500 M1/M1A1 engine.
  - Utilizes following IRAD technology elements:
    - oo Single crystal blades.
    - oo Digital ECU
  - Utilizes following TACOM fuel economy program elements:
    - oo Power turbine
    - oo Mission optimized fuel schedule
    - oo Digital ECU
    - oo Increased preload recuperator
  - Modular interchangeability - to be verified by test.(1)
  - Eliminates NBC bleed
  - Main hydraulic pump removed from engine

- o AIR FILTRATION UNIT

  - Electrically driven rotating element self-cleaning air filter.
  - Integral engine mounting.
  - Vertical mounted precleaners and rotating drum.
  - Mounting design fully interchangeable on existing M1A1.

The engine and air induction subsystem goals and compliances are as follows:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
ENGINE		
Powerpack Packaging Factor Increase	Increased	Same as ATR
Environmental Specifications Same as M1A1	Same as M1A1	Same as M1A1

(1) Results reported in Appendix I.

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
ENGINE		
Engine Idle		
Normal Idle-900 RPM	Normal Idle Same - 900 RPM	Same as ATR
TAC Idle-1300 RPM	TAC Idle - 1300 RPM	
Modular Interchangeability		
Maintain	Maintained (1) (Except Accessory Gearbox)	Same as ATR
Starting at Temperature Extremes		
Same as M1A1	Same as M1A1	Same as M1A1
Starting Attitudes		
Same as M1A1	Same as M1A1	Same as M1A1
Fuel Consumption		
10% Weighted Improvement	10% Weighted Improvement Guarantee (2)	15% Weighted Improvement Projected
Powerpack Clearance		
Maintain M1A1 Standards	Same as ATR	Same as ATR
Engine Controls		
Digital ECU w/Diagnostics	Digital ECU w/ Diagnostics	Digital ECU w/ Diagnostics
Engine Cycle Temperature		
T_7 Not to Exceed M1A1	Maximum Not Exceeded	Same as ATR

(1) Results reported in Appendix I.
(2) Textron achieved a 15.3% reduction in a TACOM witnessed test performed 20 October 1988. Results are reported in Appendix II.

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Powerpack Mounting		
Vertical Removal of Powerpack	Vertical Removal	Same as ATR
AIR INDUCTION		
Filter Life		10X Improvement Demonstrated
Same as M1A1	Over M1A1 (1)	Same as ATR
Filter Efficiency		
Same as M1A1	Same as M1A1	Same as ATR

5.2.2 Transmission and Final Drive. The ATR demonstrator transmission is an Allison Transmission Division (ATD) XT1100, Figure 5-20. The XT1100 is a transverse input, cross drive, hydrokinetic transmission with seven ranges forward and three ranges reverse, electronic shift control, hydrostatic steering, and wet multiple plate braking system. Its transfer case is designed to mount the AGT 1500 turbine engine and includes a power takeoff (PTO) accessory drive package.

The final drives are a coaxial planetary design, which are configured to adapt the XT1100 transmission to the M1A1 hull and sprocket bolt patterns.

5.2.2.1 Goals.

Transmission and Final Drive

PARAMETER	GOALS
Configuration	Mate With Transverse AGT 1500
Power Takeoff	Two Forward facing Horizontal PTOs and Two Powerpack Mounted Cooling Fan Drives
	1. 425 HP - Accessory Drive
	2. 60 HP - Spare Drive

(1) The SCAF achieved 200 hours demonstrated life in a laboratory test performed at Donaldson Co. as reported in Apendix III.

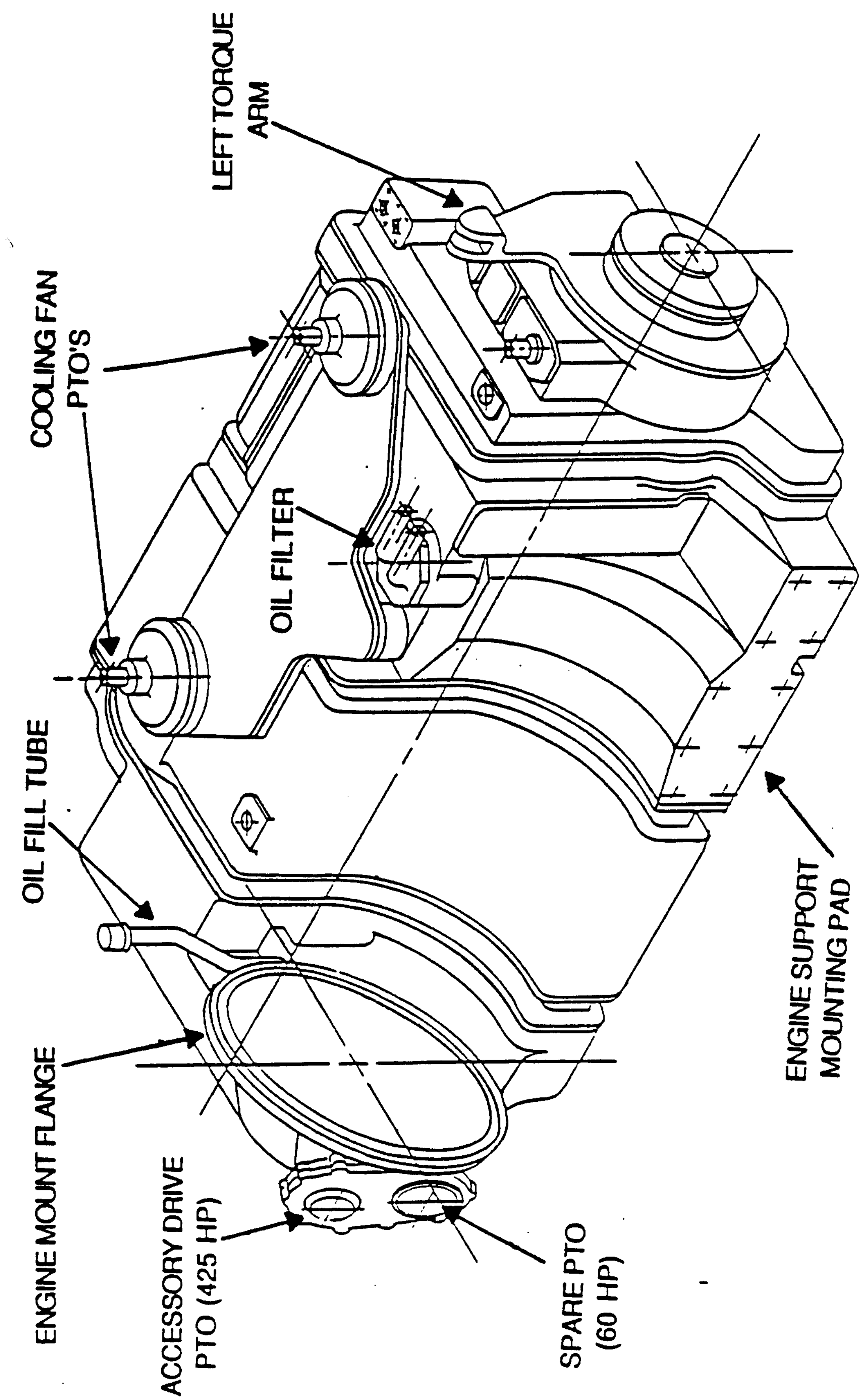


Figure 5-20. TMEPS XT1100 Transmission

PARAMETER	GOALS
	3. Two 125 HP Capability Cooling Fan Drives
Interchangeability	Maximum Extent w/X1100-3B (M1A1)
Ratios	Meet or Exceed M1A1 Performance
Steering	Meet or Exceed M1A1 Performance
Brakes	Meet or Exceed M1A1 Performance
Torque Converter	Same as M1A1
Powerpack Removal	Vertical
Dry Weight	Minimize Increase Over X1100-3B (M1A1)
Operating Environment	Same as M1A1
Final Drive Configuration	Maintain Current Mounting Configuration

5.2.2.2 Technical Approach. The transmission design guidelines were:

- o Integrate with transversely mounted AGT 1500 engine to provide a compact/dense propulsion system arrangement compared to the production M1A1 powerpack.
- o Provide mounting points for the powerpack.
- o Retain commonality with production base.
- o Provide mounting and drive mechanism for required ancillary equipment.
- o Provide cooling fan modulation for fuel economy.
- o Improve brake friction material.
- o Provide multiplexed communication data bus (with engine) capability with hardwire backup.
- o Provide increased performance and efficiency, enhanced maintainability features, and built-in-test-equipment.

The final drive design guidelines were:

- o Provide appropriate ratio reduction required to match the transmision output to achieve M1 rated top speed.
- o Provide a design which will attach to the hull identical to the current M1A1 production final drive.
- o Retain current M1A1 track sprocket.
- o Provide a saddle-type mounting for the transmission output/final drive input trunnions.
- o Retain commonality with production base.

5.2.2.3 Design Analysis.

5.2.2.3.1 Transmission. The space claim views of the XT1100 transmission are shown in Figure 5-20. The transfer case transversely mounts the AGT 1500 engine and provides the drive for powering vehicle ancillary equipment.

The torque converter is M1A1 common and is mounted on the same centerline as the range pack. Provisions are made for four PTOs which will be engine driven. The PTO pads are located as shown in Figure 5-21. Two pads have vertical drives mounted on top of the transmission and two are horizontally driven from the front of the transfer case. One PTO (425 HP) drives the accessories, the other PTO (60 HP) is a spare. Power for the cooling fan PTOs is taken from the torque converter input by a bevel gear set and transfer gearing. These cooling fan drives are clutchable for fuel economy and water fording.

Steering is accomplished by an M1A1 common hydrostatic unit in the XT1100 center section assembly, with a variable displacement pump, fixed displacement motor of radial piston design. The speed ratio of the steering unit is proportional to the pump displacement with system pressure dependent upon resistance to steer.

A gear and bearing design life analysis showing a comparison of componentry lives with the M1A1 X1100 transmission was accomplished and is summarized as follows:

TRANSMISSION SUBSYSTEM DESIGN ANALYSIS
GEAR AND BEARING LIFE ANALYSIS

	M1A1 63 TONS AGT 1500 1122 NHP X1100			M1A1 65 TONS AGT 1500 1358 NHP XT1100-3B			M1A1 65 TONS AGT 1500 1358 NHP XT1100	
P/N	NAME	PERCENT*	P/N	NAME	PERCENT	P/N	NAME	PERCENT
	P2 SUN GEAR	100		P2 SUN GEAR	93		P3 NEEDLE	94
11669546	TIMKEN BRG	100	11669546	TIMKEN BRG	93		TAPERED BRG	100
11669544	TIMKEN BRG	103	11669544	TIMKEN BRG	97		P4 NEEDLE	125
	P1 NEEDLE	109		P1 NEEDLE	98		P5/P6 NEEDLE	136
12267994	HYATT BRG	106	12267994	HYATT BRG	99		P2 SUN GEAR	137
	P2 NEEDLE	109		P2 NEEDLE	101		ROLLER BEARING	171
**	TOTAL TRANSMISSION	100		TOTAL TRANSMISSION	90		TOTAL TRANSMISSION	98

* PERCENT LIFE OF X1100 M1A1 LOWEST LIFE COMPONENT
** PERCENT LIFE OF X1100 M1A1 TRANSMISSION

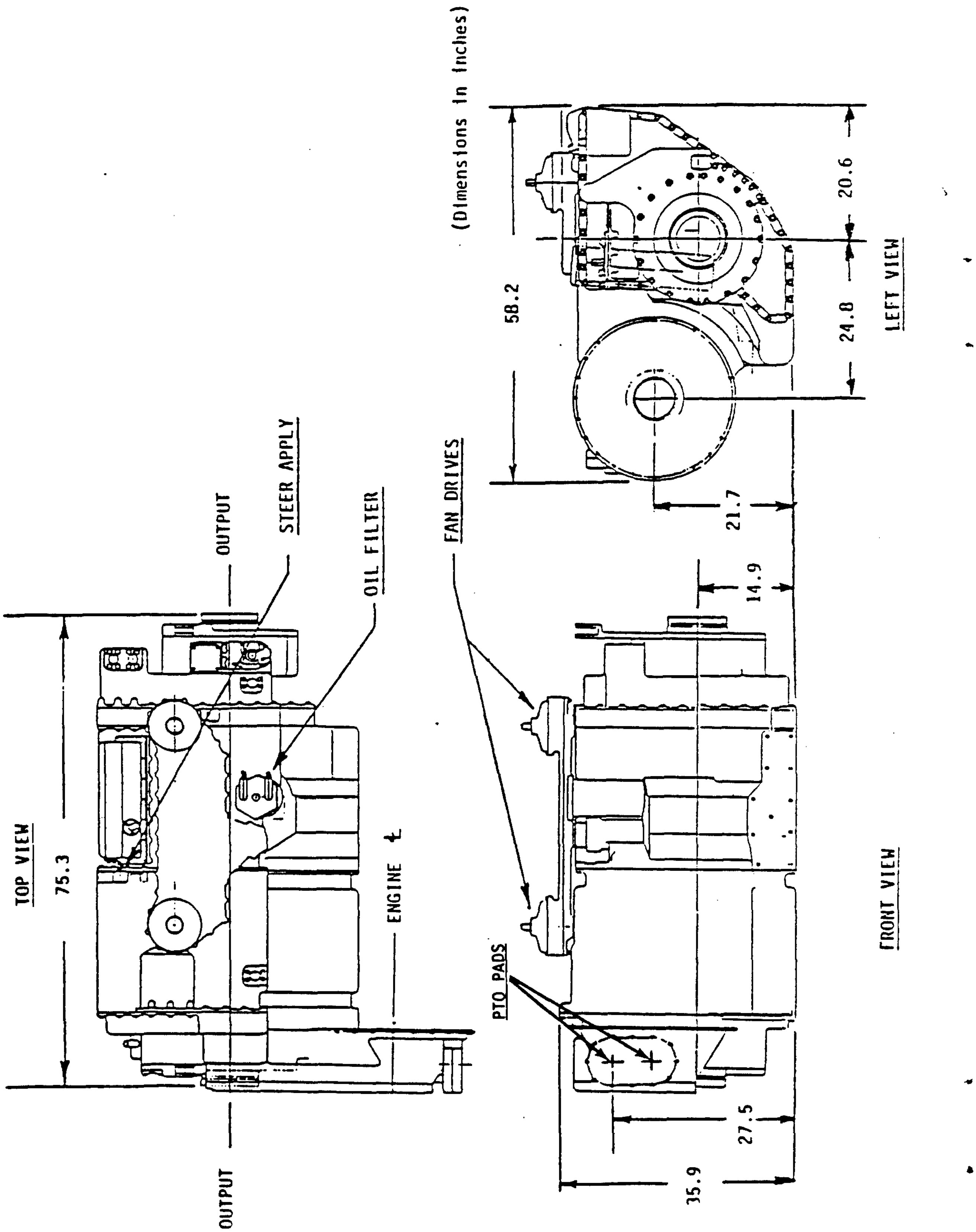


Figure 5-21. XT1100 Transmission Envelope

The range pack provides seven forward and three reverse ranges. The selection of the range package was a function of the sprocket power required, (Figure 5-22). A comparison of TMEPS vs. M1A1 transmission characteristics are shown in Tables 5-1 and 5-2.

The transmission hardware common between the (XT1100 and X1100-3B) is:

Torque converter, TC897
Hydrostatic steer unit
Steer system controls
Output planetaries
Oil filter assembly (M1)

In a breakdown by part number, the production commonality is 46 percent.

5.2.2.3.2 Final Drive. The final drive design is simmilar to the current M1A1 hardware. Mounting to the hull is identical to the M1A1. Final drive commonality is:

- o Output Bearing
- o Output Seal
- o Disconnect System

The ATR demonstration final drive is designed to provide the appropriate reduction ratio required to match the XT1100 transmission output speed to the desired rated vehicle top speed. This reduction is achieved with a simple planetary unit having a ratio of 5.067:1. A schematic of the final drive is shown in Figure 5-23.

5.2.2.4 Tradeoffs.

Transmission

A range pack option performance comparison provided a criterion for selecting a seven-speed range pack for the XT1100 is as follows:

	X1100-3B 4-SPEED	POTENTIAL 6-SPEED	XT1100 7-SPEED
MECHANICAL RATIO COVERGE (x:1)	4.6	5.9	8.3
AVG. SPROCKET HP (1305 NHP IN)	1044	1106	1130

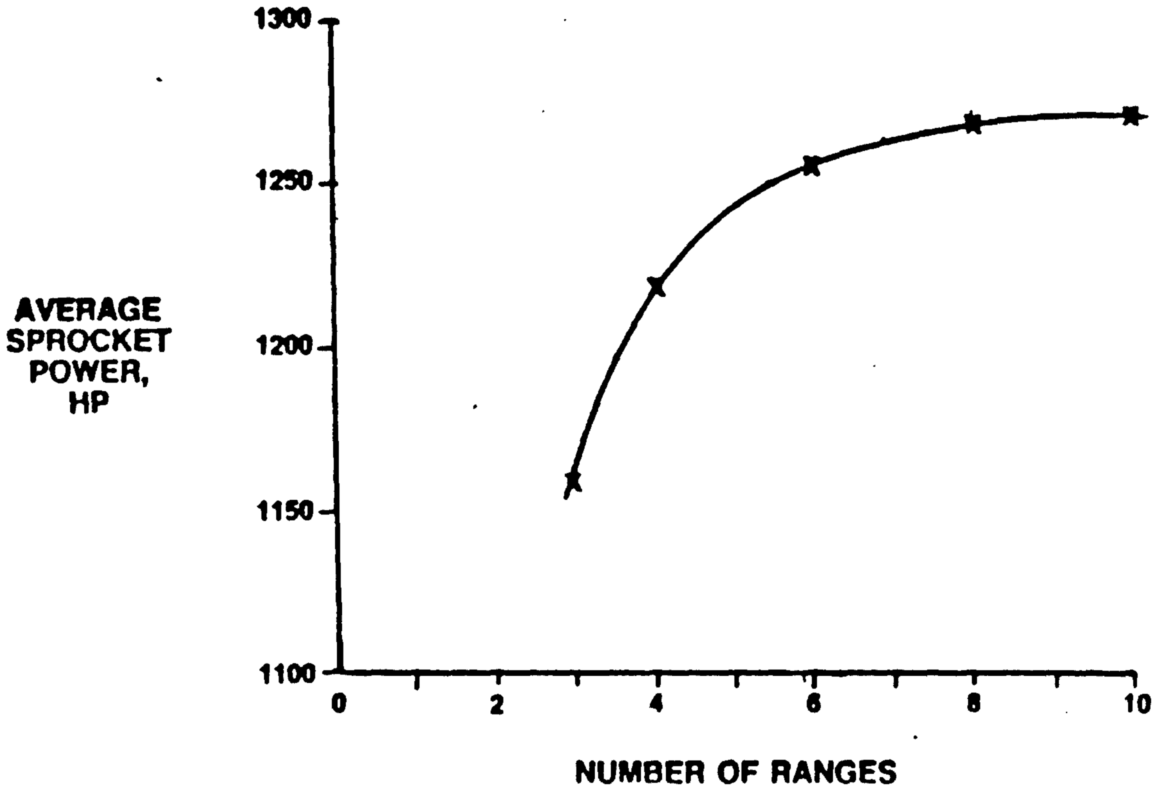


Figure 5-22. Range Number Optimization

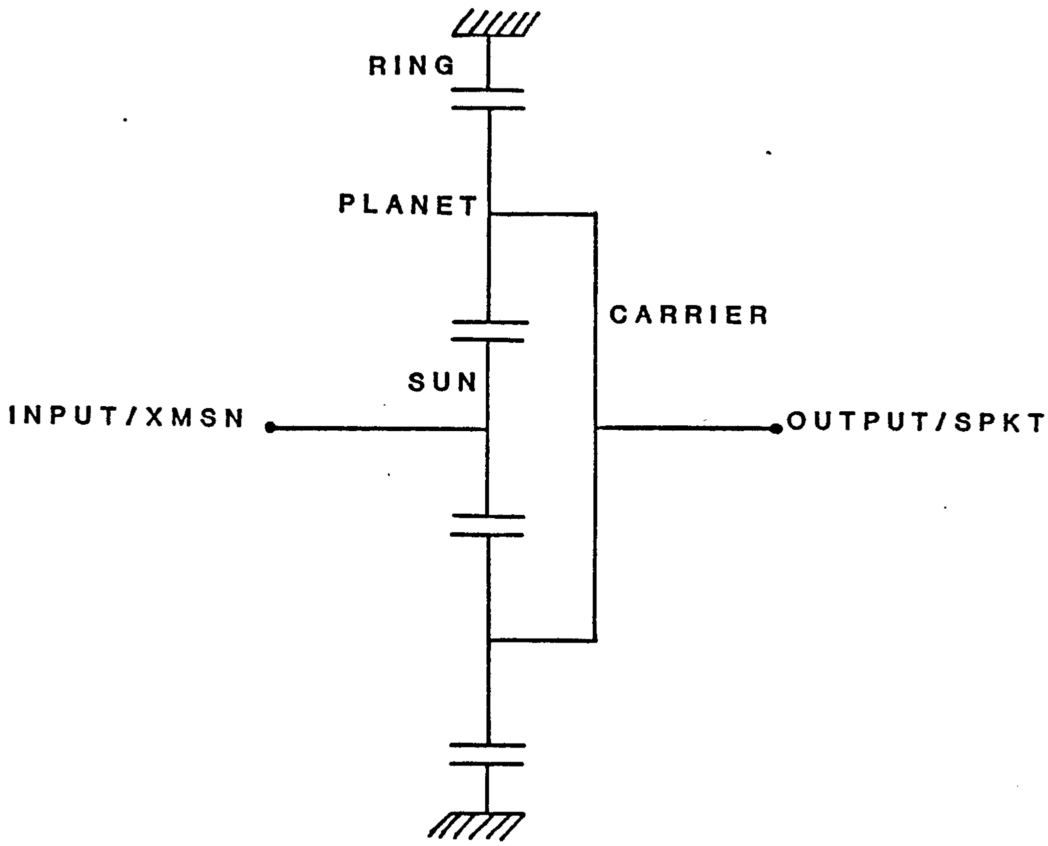


Figure 5-23. XT1100 Final Drive Schematic

TABLE 5-1 TRANSMISSION FEATURES COMPARISON

	X1100-3B	XT1100
INPUT DRIVE	T-DRIVE	TRANSVERSE
NO. RANGES: FORWARD/REVERSE	4/2	7.3
FINAL DRIVE	M1A1 (4.67:1)	NEW (5.07:1)
RANGE CONTROLS	ELECTRIC - HYDRAULIC	ELECTRONIC
BRAKES	OIL COOLED FRICTION PLATES	OIL COOLED FRICTION PLATES
MAXIMUM VEHICLE SPEED (MPH)	41.96	45.0
TRACTIVE EFFORT	150,170	252,968
VEHICLE WEIGHT	63.2 TONS	65 TONS
TE/WT AT 65 TONS	1.19	1.95
COOLING SYSTEM	TWO AXIAL FANS MECHANICALLY-DRIVEN NOT MODULATED	TWO CENTRIFUGAL FANS MECHANICALLY -DRIVEN MODULATED
MAXIMUM HEAT REJECTION (125° DAY) (BTUs/MIN AT RPM)		
- AT .7 TE	11382 AT 1692	4565 AT 1743
- AT MAXIMUM SPEED	9978 AT 3075	9864 AT 3075
FLUID	MIL-L-2104C GRADE 30	MIL-L-2104D 15W40

Table 5-2. Transmission Range Comparison

M1A1

	1st	2nd	3rd	4th
GEAR RATIO	5.8773	3.0207	1.8909	1.2777
GEAR EFFICEINCY	94.67	94.42	95.36	95.85
GEAR STEP SIZE		1.9457	1.5975	1.4799
GEAR INERTIA	106.6	24.06	11.67	9.75 (lb-ft-sec**2 xmsn output)
STEER RATIO	2.34	1.52	1.30	1.19
STEER RADIUS (ft.)	19.1	37.1	58.7	88.3

RATIO COVERAGE MECHANICAL - 4.6
RATIO COVERAGE (WITH TORQUE CONVERTER) - 9.9

	TE (lbs)	TE/GVW=65 tons
90 F @ 2000 ft.	140,157	1.08
87 F @ 500 ft	149,031	1.15

TMEPS

	1st	2nd	3rd	4th	5th	6th	7th
GEAR RATIO	8.9533	5.6455	3.7101	2.4486	2.0217	1.5153	1.0798
GEAR STEP SIZE		1.5859	1.5217	1.5152	1.2112	1.3342	1.4033
GEAR EFFICEINCY	96.19	96.39	96.54	96.95	97.35	96.50	96.2
GEAR INERTIA	164.4	61.0	26.5	14.0	11.6	7.5	5.2
(lb-ft-sec**2 @ xmsn output)							
STEER RATIO	6.72	2.75	1.89	1.51	1.40	1.29	1.20
STEER RADIUS (ft.)	10.3	16.4	24.9	37.7	46.0	60.5	84.3

RATIO COVERAGE MECHANICAL - 8.3
RATIO COVERAGE (WITH TORQUE CONVERTER) - 17.8

	TE (lbs)	TE/GVW=65tons
90 F @ 2000 ft	249,457	1.97
87 F @ 500 ft	265,867	2.05

5.2.2.4 Tradeoffs.

Transmission

A range pack option performance comparison provided a criterion for selecting a seven-speed range pack for the XT100 is as follows:

	X1100-3B 4-SPEED	POTENTIAL 6-SPEED	XT1100 7-SPEED
MECHANICAL RATIO COVERAGE (x:1)	4.6	5.9	8.3
AVG. SPROCKET HP (1305 NHP IN)	1044	1106	1130
MAX. FWD. SPEED (MPH)	41.5	45	45
MAX. REV. SPEED (MPH)	20	13	20
PEAK TE/GVW (STALL)	1.18	1.34	1.99
HEAT REJ. @.7 TE/W (BTU/MIN)	13644	9816	4772
NO. ROTATING CLUTCHES/TOTAL NO. CLUTCHES	2/5	3/6	2/6

An analysis of the cooling fan drive alternatives resulted in the selection of mechanical gear drive with disconnect clutches based on the following assessment:

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Hydrostatic Drive	o Constant Speed Cooling Fans o Minimum Gear Train (Oil Flow Lines Flexible)	o External Hydraulic Lines o Requires Hydrostatic Pump Control o Incresed Cost
Mechanical Gear Drive	o Simple Design - Low Technical Risk	o Fan Speed Varies with Input Speed o Maximum Power Loss at Fan Maximum Speed o Large Number of Gears

CONFIGURATION		ADVANTAGES		DISADVANTAGES
Mechanical Drive Disconnect Clutches	o	Known Technology - Low Risk	o	Requires Addition of Rotating Clutch, Control, and Hydraulic
	o	Allows Disengaging Second Fan When Cooling not required (Reduced Power Loss)	o	Apply Cores in Transmission
Mechanical Drive with Fluid Coupling Disconnect	o	Moderate Technology Risk	o	Requires Addition of Coupling, Controls, and Large Volume Feed Cores to Coupling in the Transmission

An assessment of the braking system resulted in selection of wet friction plate brake configuration based on the following:

Hybrid: Retarder and Wet Plate	o	Reduced Spin Loss	o	More Complex Controls
	o	Reduced Elements		Wear
	o	Adjustment Not Required	o	May Increase Oil Flow Passage Requirements
	o	Allows More Packaging Options	o	Reduced Capacity in Mechanical Backup
Wet Friction Plate	o	High Degree of Commonality with X1100-3B	o	May Require Adjustment
	o	Simple Controls - Common with X1100-3B	o	Generates Wear Particles
	o	High Capacity Parking Brake	o	Higher Spin Losses
	o	Simplified Oil Flow Path		

CONFIGURATION	ADVANTAGES	DISADVANTAGES
	o Vast Production Experience	
	o Simplified Diagnostic and Repair Procedure	

A three brake shaft system was selected based on the following assessment:

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Two Shaft	o Emergency Braking With the Service Brake Pedal	o Requires New Vehicle Linkages
	o Reduces the Required Hardware Internal to the Transmission	o Nonlinear Service Brake Mechanism is required
Three Shaft	o Uses Current Vehicle Linkages	o Requires the Use of the Parking Brake System for Emergency Braking

Final Drive

The final drive removable hub versus integral (fixed) drive sprocket design is compared in Figure 5-24.

The selection of the final drive removable hub versus integral (fixed) drive sprocket design was based on the following:

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Integral Sprocket Hub	o Allows Increased Planetary Length	o New Inboard Sprocket Required (2 Piece)
	o More Ratio Flexibility with Compound Planetary	o Increased Length/Weight
		o Utilizes 10% of Current P/Ns

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Removable Sprocket Hub	o Utilizes 50% of Current P/Ns o Output Seal and Bearing Design Proven o Utilize Current M1A1 Hub and Sprocket	o Limited Ratios Available

5.2.2.5 Selected Design. The following is a summary of the selected transmission and final drive design which conforms to the vehicle performance requirements:

- o Input configuration is transverse for AGT 1500
- o Two accessory drive PTOs
  - one forward facing PTO (425 HP) to drive accessories
  - one forward facing PTO (60 HP) as spare drive
- o TC 897 series torque converter (Same as M1A1)
- o Fan Drive System
  - Two mechanical PTO fan drive systems
  - PTOs are clutchable for fuel economy
  - PTOs driven by a separate ancillary gear case mounted onto the transmission
- o Incorporate M1A1 hydrostatic steer drive
- o Controls
  - Digital electronic control unit
  - Embedded diagnostics
  - Steering, brakes
  - True pivot steer
- o Final drive trunnion/hull rear torque arm mounting system
- o 46 percent commonality with X1100-3B (M1A1)
- o Incorporate simple planetary final drive with M1A1 removable sprocket hub.

The transmission and final drive is in compliance with the following:

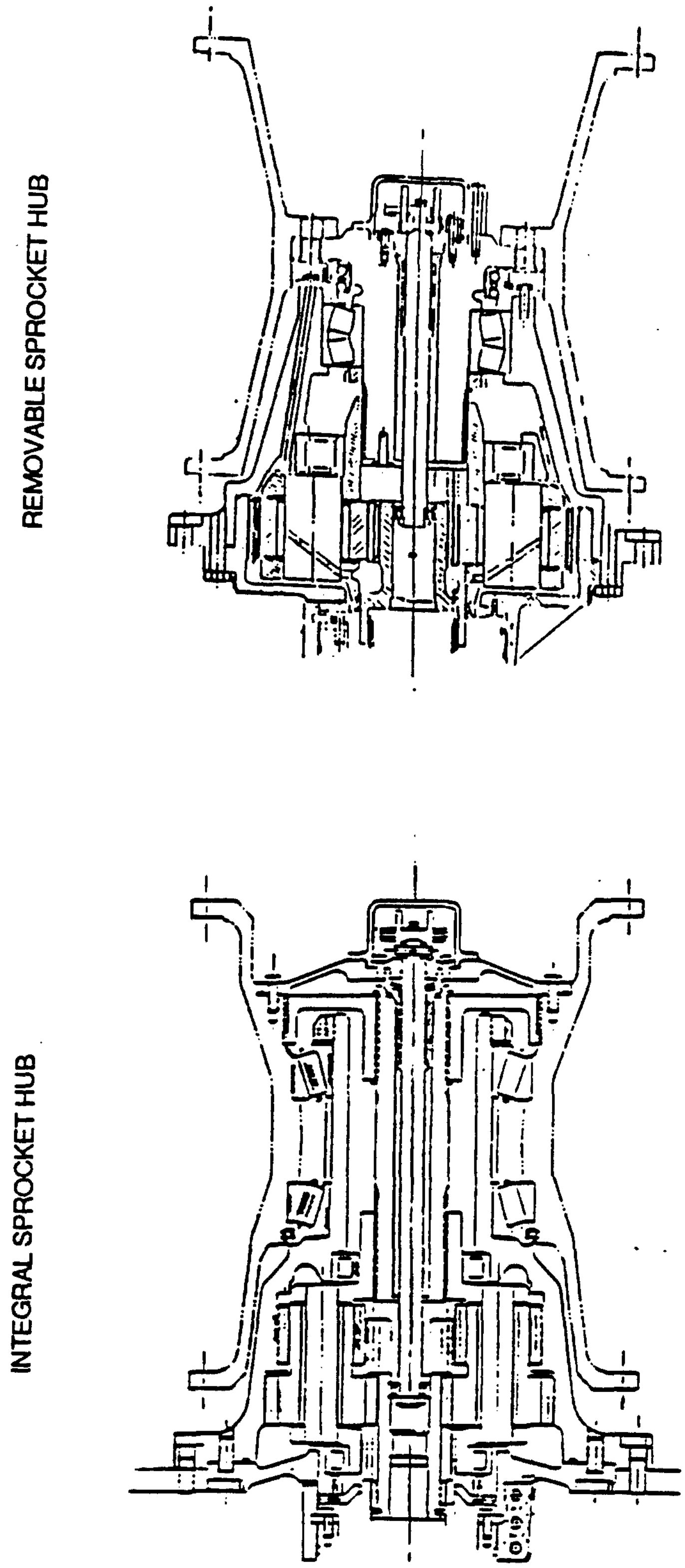


Figure 5.24. Final Drive Sprocket Design

GOAL	ATR TMEPS	M1-TMEPS (FUTURE)
Configuration		
o Transverse	Transverse	Same as ATR
Power Take-offs		
o 425HP Accessory Drive	425HP Accessory Drive	Same as ATR
Power Take-offs (Continued)		
o 60 HP Spare Drive	60 HP Spare Drive	
o 60 HP Spare Drive	60 HP Spare Drive	
Interchangeability		
o Maximize Commonality with X1100-3B (M1A1)	46% Commonality with X1100-3B (M1A1)	Up to 58%
Ratios		
o Necessary to Meet or Exceed M1A1 Performance	7-Speeds Forward 3-Speeds Reverse Ratio Coverage is Higher than M1A1	6-Speeds Forward 2-Speeds Reverse
Steering		
o Meet or Exceed M1A1 Performance	TMEPS Min. Steering Radius - 10 Ft	Same as ATR
Brakes		
o Meet or Exceed M1A1 Performance	Exceeds M1A1	Same as ATR
Powerpack Removal		
o Vertical Removal	Vertical Removal	Same as ATR
Operating Environment	Same as M1A1	Same as M1A1
Final Drive Configuration	Bolts Directly to Current M1A1 Hull	Same as ATR

GOAL	ATR TMEPS	M1-TMEPS (FUTURE)
Torque Converter	Same as M1A1	Same as M1A1

5.2.3 Auxiliary Power Unit and Accessory Drive. The auxiliary power unit (APU), Figure 5-25, provides electrical power and pressurized air for the NBC system when the main engine is not operating. An addditional APU benefit is main engine cold start assistance by recharging the batteries and providing alternator output for the main engine starter. The APU is located under armor. The accessory drive system interfaces with both the APU and the transmission PTO to supply a constant speed drive for the following accessory systems:

- o NBC Compressor
- o Alternator
- o SCAF Compressor
- o Scavenge Blower
- o Hydraulic Pump

Accessibility to the APU and accessory drive system is at the top deck access panel or engine compartment bulkhead.

5.2.3.1 Goals.

PARAMETER	GOALS
APU	John Deere Rotary Diesel (80 HP) Including: - Engine with Starter - Electrical System Less Battery - Fuel Conditioning - Cooling System or Provision for External Cooling - Air Filter or External Provision
NBC Output	Compressor Providing Continuously 200 - 230 SCFM 38 PSIG Minimum
Electrical Output	Five Kilowatts Between 18 and 30 Volts DC

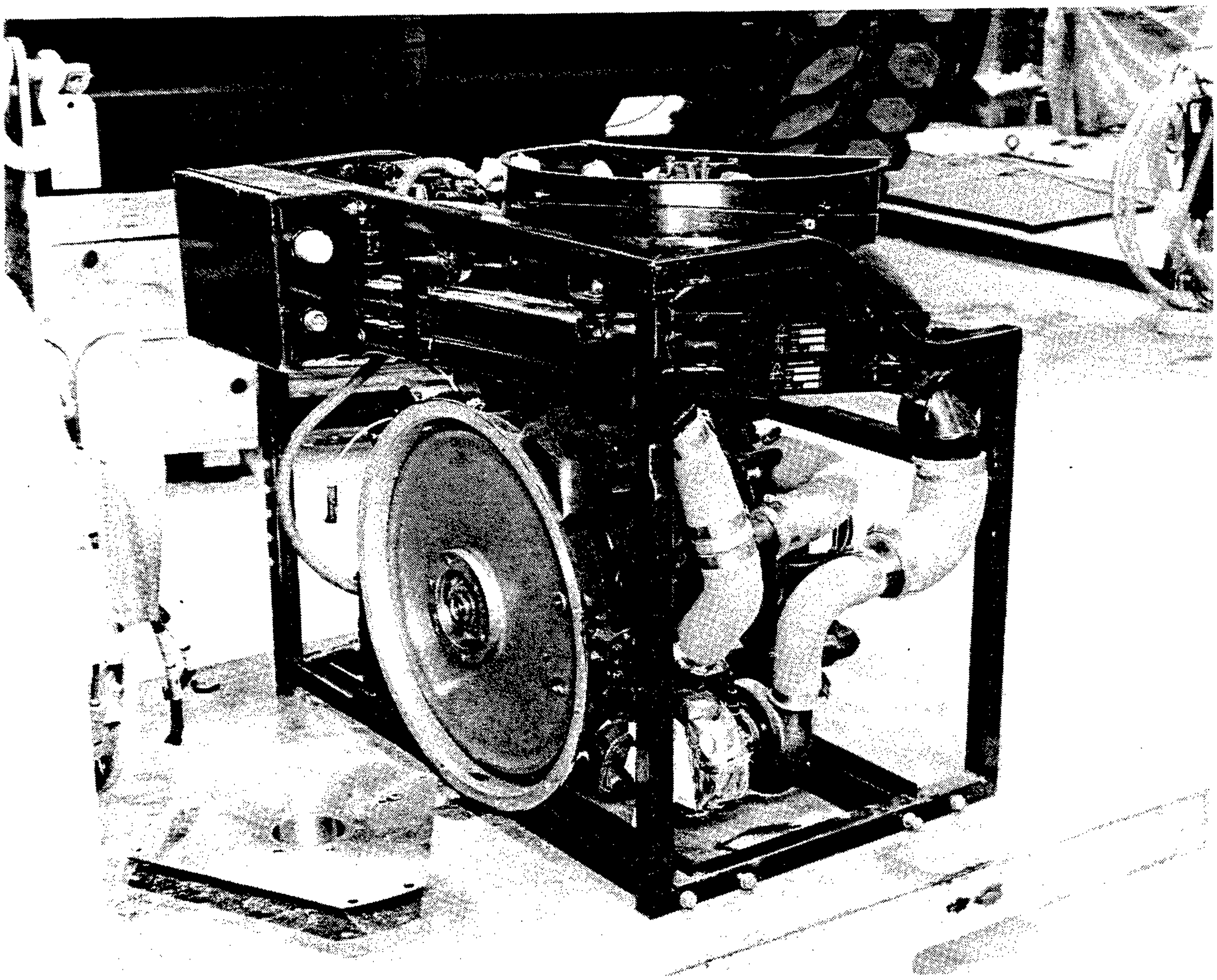


Figure 5-25. Auxiliary Power Unit

Accessory Drive	Provide Constant Speed Accessory Drive for the Following Systems:

- o During Main Engine Operation
  - SCAF Compressor
  - NBC Compressor
  - Alternator
  - Scavenge Blower
  - Hydraulic Pump
- o During APU Operation
  - NBC Compressor
  - Alternator

PARAMETER	GOALS
Size	APU - 11 Cubic Feet Maximum
Environmental Specifications	Same as M1A1
Weight	Minimize Weight Impact

5.2.3.2 Technical Approach.

Auxiliary Power Unit. The design considerations were:

- o Provide 18KW of direct current (DC) power and full NBC protection during APU operation.
- o Use fuel at the rate of 3.7 gallons/hour at nominal power requirements.
- o Provide interface with control/display in driver's station.
- o Provide common air supply for main engine and APU.

Accessory Drive. The design considerations are to obtain the following operating characteristics:

- o Provide dual source drive for accessories.
- o Provide a constant speed output as input speeds vary from 1800 RPM (idle) to 6300 RPM (100 percent) from the transmission PTO.

The power required for the accessory drive components is as follows:

Component	Horsepower	Speed (RPM
o Scavenge Blower	3.1	5693
o Alternator	38.0	3000
o Hydraulic Pump	50.0	3750
o NBC Compressor	40.0	13069
o SCAF Compressor	25.0	4941

5.2.3.3 Design Analysis.

Auxiliary Power Unit

The John Deere APU is used to supply power to drive accessories. The design meets TMEPS requirements for power (80-100 HP) and volume not exceeding 11 cubic feet.

The APU is a single rotor stratified charge engine designated as SCORE 70, Model 1007R. It will be coupled to the accessory drive and will be self sufficient in operation. The following are its characteristics:

Displacement	0.7 liters
Weight	198 lbs (less cooling system)
Volume	5.35 cubic feet
Rated speed	6,000 RPM
Rated power	80BHP (60KW)
Compression ratio	8.5 to 1
Turbocharger pressure ratio	2.2 to 1
Ignition	Spark Assisted Stratified Charge

The APU includes an integral heat exchanger and a cooling fan. In comparison to the naturally aspirated engine, the selected turbocharged/intercooled configuration provides:

- o Increased power density
- o Improved nominal fuel economy
- o Lower exhaust gas temperatures
- o Stable power level at varying altitudes

The APU impact on TMEPS fuel consumption for a Peacetime Annual Usage with NBC ON/OFF is:

Configuration	Fuel NBC-ON Gallons	Fuel NBC-OFF Gallons
TMEPS with APU	3772	3163
TMEPS without APU	5240	4222

The APU is integrated in the space previously occupied by the M1A1 hull ammo rack and will occupy 11 cubic feet. A screen for cooling air inlet is provided in the top deck.

Crew accessibility to the APU cool and air filter will be through a top deck door. Powerpack removal is required in order to remove the APU.

The concept of a common air filtration system for the APU and powerpack versus a separate system was evaluated as follows:

- o APU air supplied by SCAF system eliminates need for additional APU precleaner.
- o Deep water fording requires less preparation with SCAF than a conventional filter system and allows for APU operation during fording if necessary.
- o SCAF requires less maintenance than conventional filter system.
- o Separate systems do not require as much ducting.

The common air filtration system is used. The APU contains a barrier filter for operation when the powerpack and SCAF is removed.

The NBC airflow/compressor sizing analysis was as follows:

- o Prioritization valve on the current M1A1 regulates variable pressure into the NBC from the powerpack.
- o A constant output compressor eliminates the need for a prioritization valve.
- o Removal of the prioritization valve reduces the pressure requirement from 44 to 35 psig.

The NBC compressor characteristics are:

Airflow and Pressure	-	215 $\pm$ 15 SCFM at 35 psig
Size and Weight	-	Less then one cubic foot and 55 lbs.
Cooling	-	Oil
Efficiency	-	Approximately 70%

Alternator

The alternator requirements established are:

Rated output	-	15 KW
Voltage DC	-	28

The M1A1 alternator provides sufficient power for the ATR where a load study revealed power requirements of:

- o Silent watch electrical load, 1.8 KW
- o Nominal electrical load, 6.1 KW

The alternator power rating was chosen to provide growth capability.

Vehicle Accessory Gearbox (VAG)

The vehicle accessory gearbox with a continuously variable transmission (CVT) provides a constant speed drive to all the accessory components. The CVT incorporats a torodial disk design which is an off-the-shelf item supplied by the Self Changing Gears Ltd. The CVT supplies a constant 2700 RPM input to the vehicle accessory gearbox from the powerpack PTO, where speeds vary from 1800 to 6300 RPM. The vehicle accessory gearbox is also required to be driven by the APU and provide a constant output speed to the NBC compressor and alternator.

5.2.3.4 Tradeoffs. The continuously variable transmission drive was compared with the following design alternatives:

Alternative	System Description	Evaluation
Hydrostatic Drive System (Figure 5-26)	Hydraulic pump and motor provides constant speed into vehicle accessory gearbox	Requires an additional reservoir, heat exchanger and plumbing (increase space claim weight). Low efficiency.
Direct Drive (Figure 5-27)	Drive shaft from transmission PTO to vehicle accessory gearbox. Provides variable speeds to accessories	Degraded accessory performance at less than main engine full rated speed.
Multiple Speed Transmission Drive (Figure 5-28)	Driven by the transfer case PTO, provides constant speed	Requires additional development time for TMEPS application.

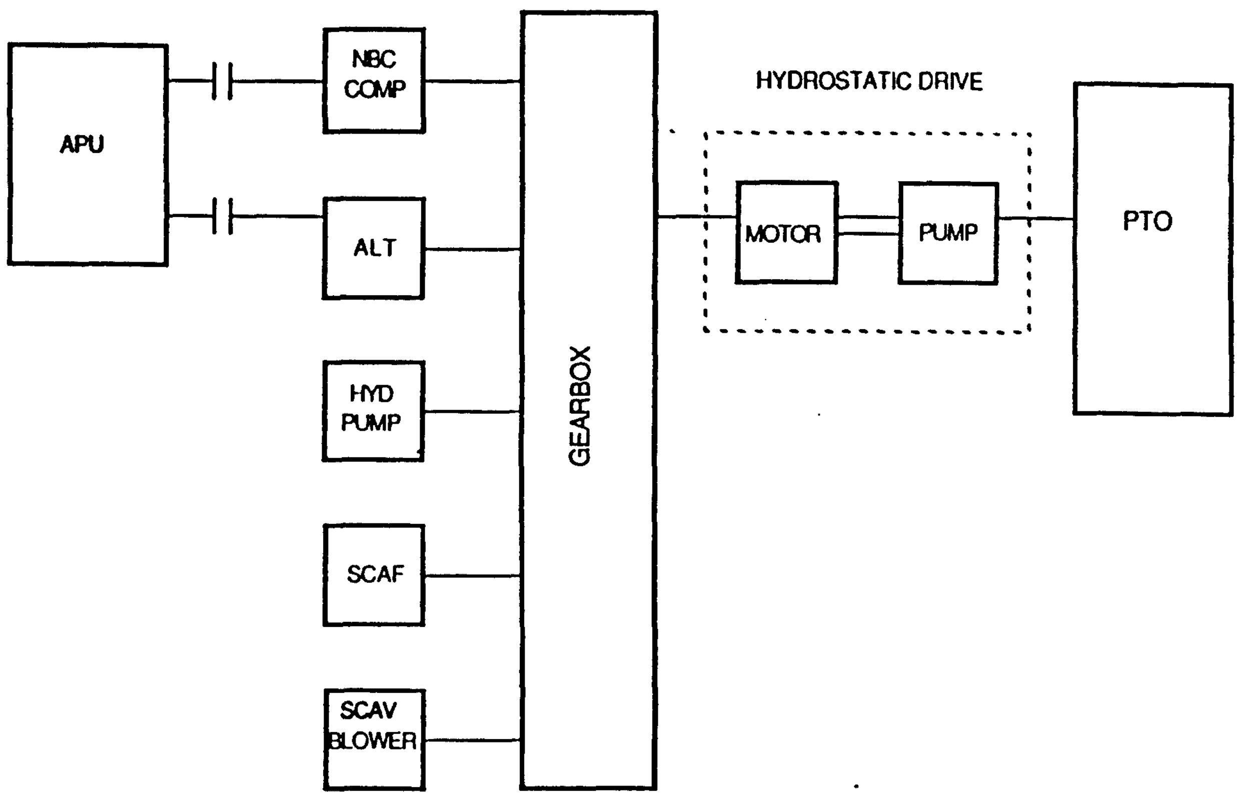


Figure 5-26. Hydrostatic Drive System

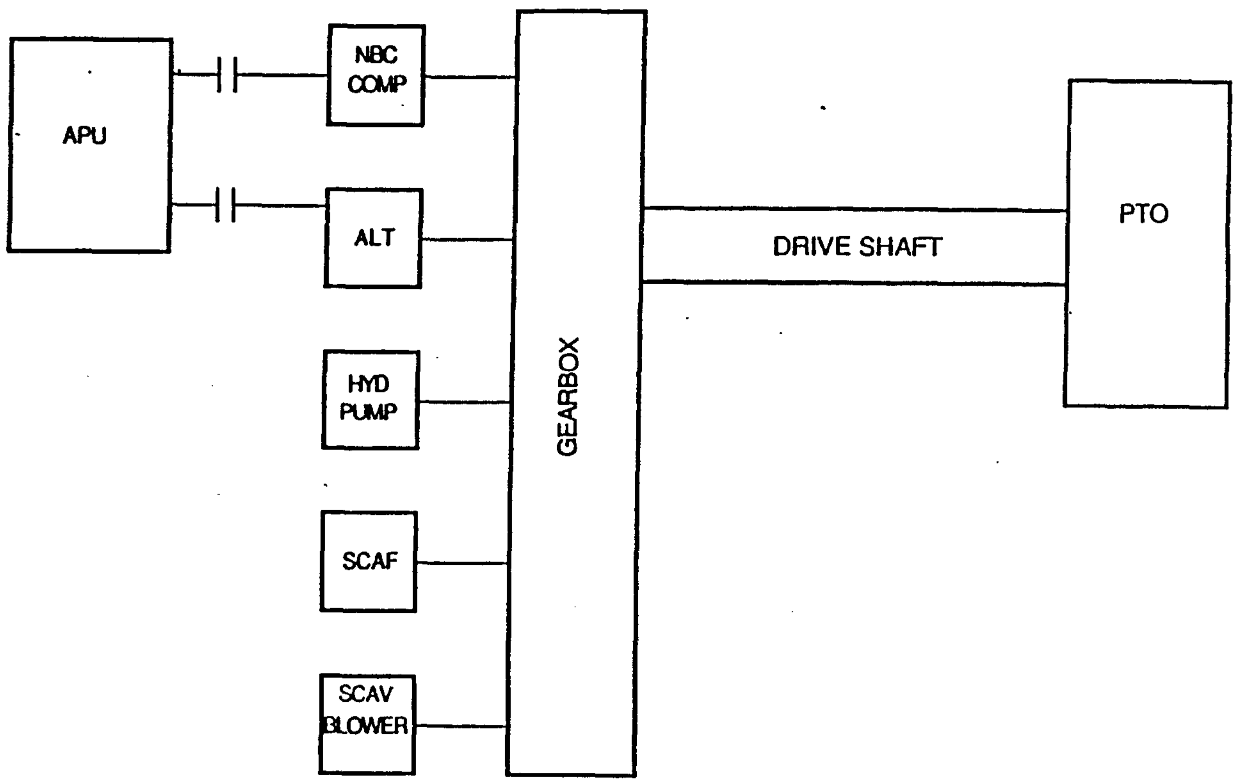


Figure 5-27. Direct Drive System

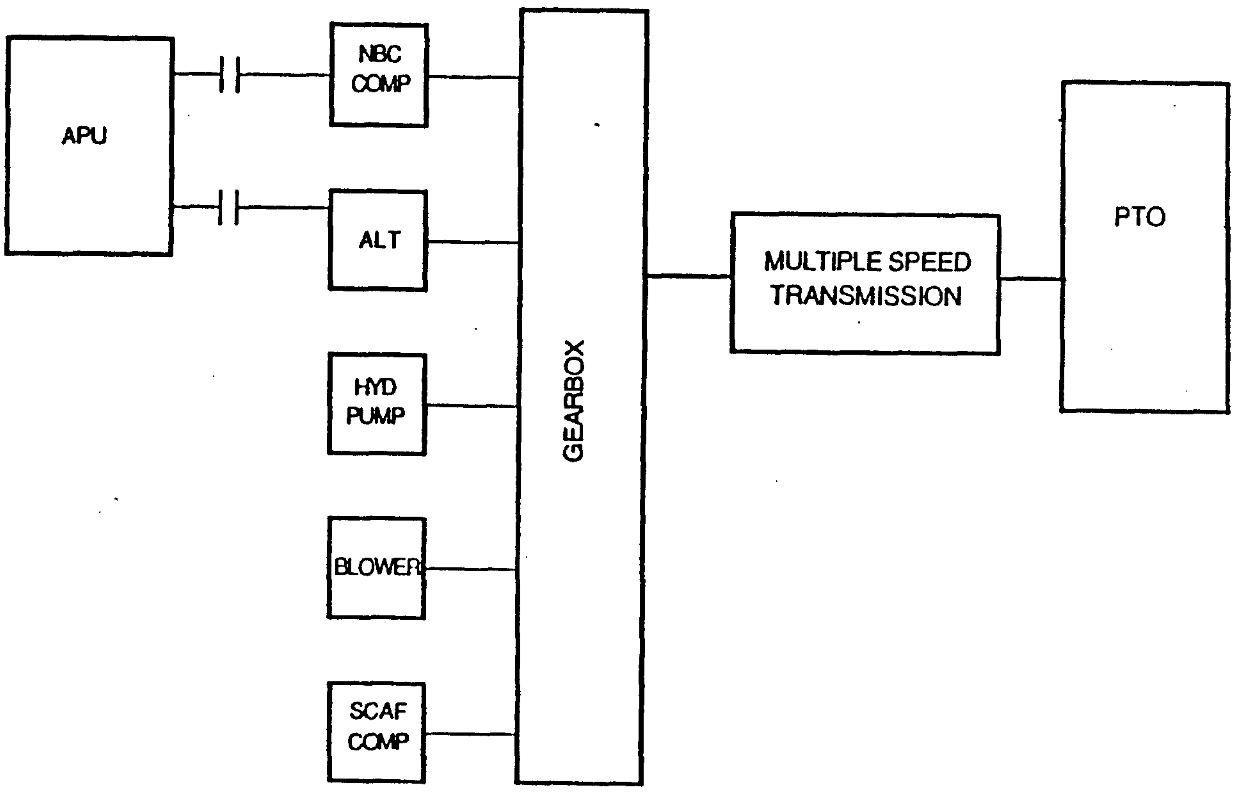


Figure 5-28. Multiple Speed Transmission Drive System

Alternative	System Description	Evaluation
Bleed Air and Direct Drive Gearbox (Figure 5-29)	Main engine bleed air operates NBC and SCAF Systems. Direct drive gearbox powers alternator, scavenge blower and hydraulic pump. APU operates NBC compressor and alternator when main engine is off.	Impacts space claim and weight requirements. Impacts main engine internal operating temperatures.
Multiple Power Supply (Figure 5-30)	Main engine to power a direct drive gearbox. APU operates concurrently with main engine.	Degrades performance at low engine speeds. Impact on weight and space claim.
Transmission Accessory Drive (Figure 5-31)	Add accessory drives to transmission case. Integrates a CVT to the transmission - provides constant speed output.	Increased hull packaging flexibility.
Direct Drive and Hydrostatic Drive (Figure 5-32)	During main engine operation, transfer case PTO powers a direct drive gearbox and a hydrostatic unit. Direct drive gearbox operates the scavenge blower, hydraulic pump and alternator. Hydrostatic unit would power the NBC and SCAF compressor. APU would power a separate NBC compressor and alternator.	Requires additional compressor and alternator. Impacts space claim and weight and complexity.

5.2.3.5 Selected Design. The selected design includes the following:

- o John Deere Score 70 Rotary Engine (80 HP)
- o Self Contained Cooling System For APU

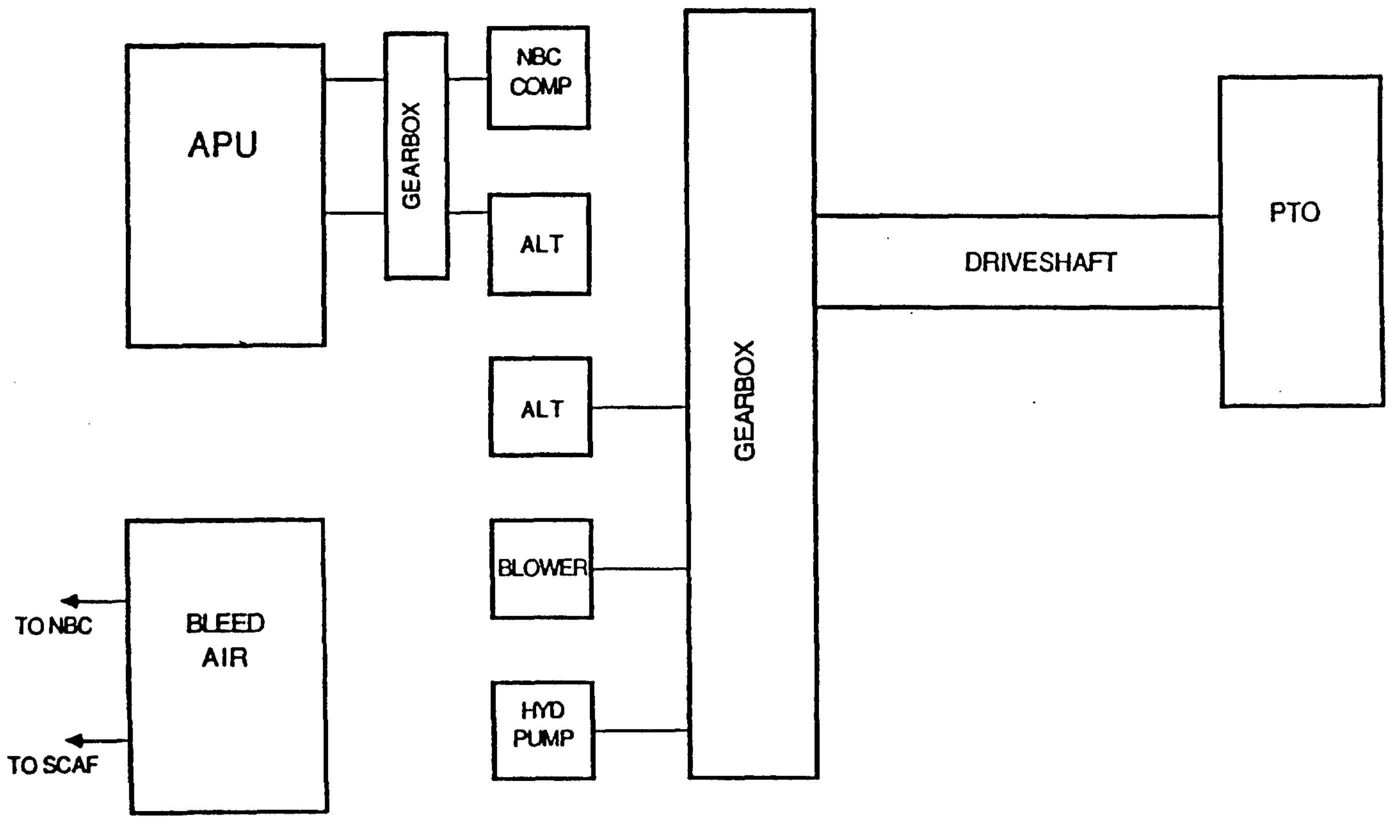


Figure 5-29. Main Engine Bleed Air and Direct Drive Gearbox System

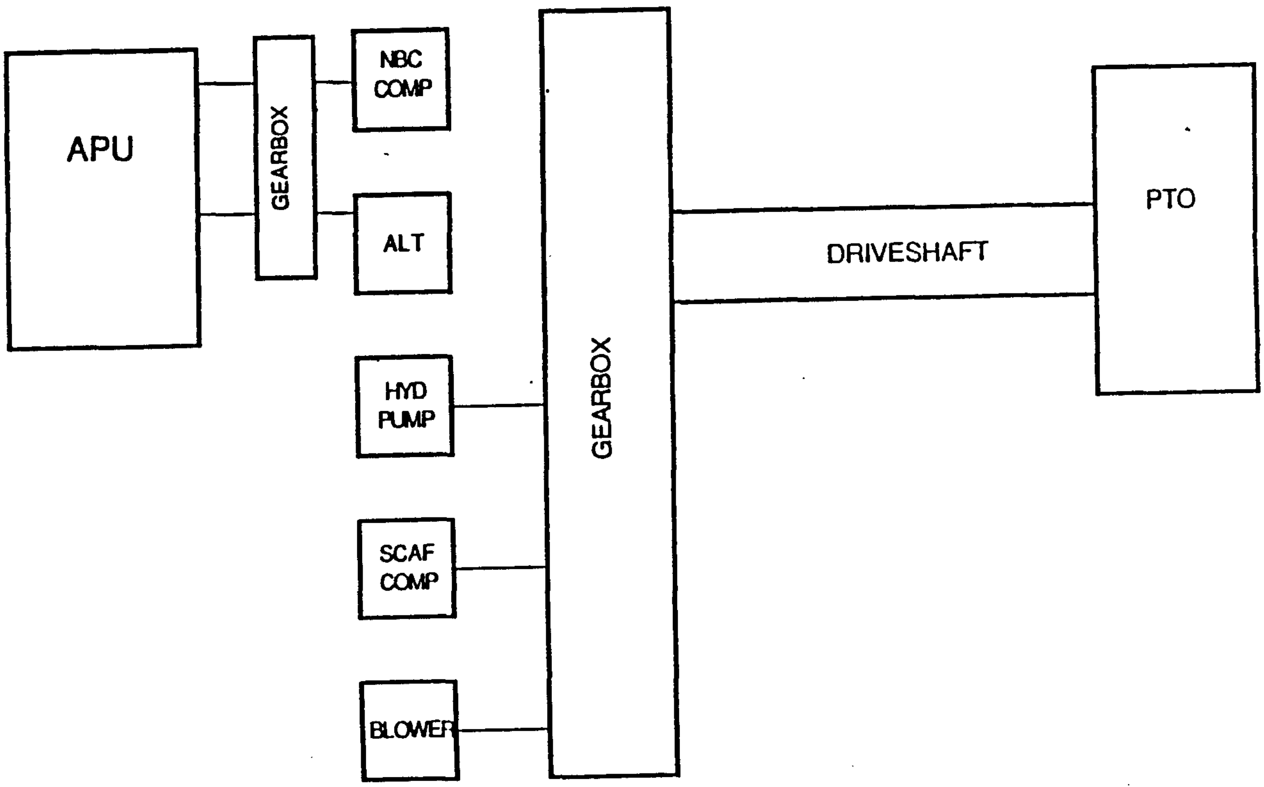


Figure 5-30. Multiple Power Supply System

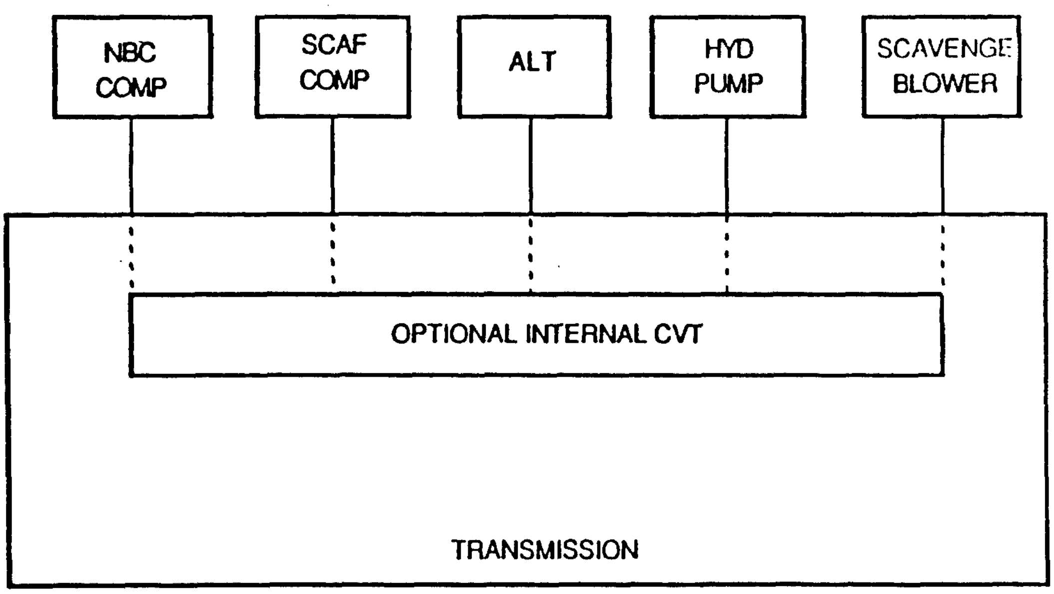


Figure 5-31. Transmission Accessory Drive System

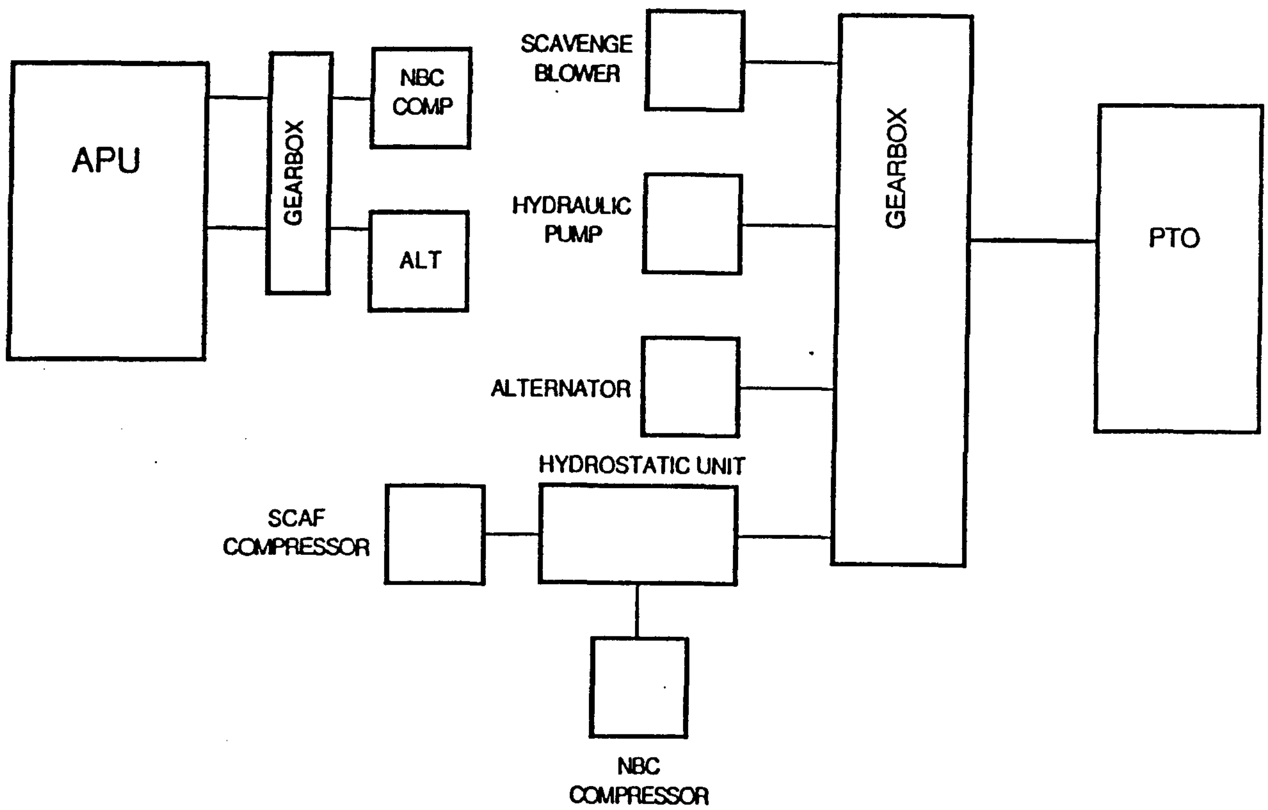


Figure 5-32. Direct Drive and Hydrostatic Drive System

- Engine Coolant
  - Vehicle Accessory Gearbox (During APU Operation)
  - Accessories
  - Intercooler for Turbocharger

o Stand Alone Fuel Conditioning System

  - Transfer Pump
  - Fuel/Water Separator
  - Filters

o Air Source for APU and NBC Provided by SCAF System

  - Additional Barrier Filter Included on APU and NBC Compressor for Periods When Powerpack is Removed

o Vehicle Accessory Gearbox with Continuously Variable Transmission for Constant Speed Accessory Drive During Main Engine Operation or APU Operation

  - NBC Compressor
  - Alternator
  - SCAF Compressor
  - Scavenge Blower
  - Hydraulic Pump

o 18 Kilowatt Alternator

o Accessibility to APU and Accessory Drive

  - Top Deck Access Panel
  - Engine Compartment Bulkhead

The auxiliary power unit and accessory drive compliances are:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
System		
John Deere Rotary	John Deere Rotary	Rotary Diesel
NBC Output		
200-230 SCFM	200-230 SCFM	200-230 SCFM
38 Psig Minimum	38 Psig Minimum	38 Psig Minimum
Electrical Output		
5 Kilowatts	18 Kilowatt Alternator	5 Kilowatt Alternator

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Constant Speed	Self Changing Gears	Self Changing Gears
Accessory Drive	Continuously Variable Transmission	Continuously Variable Transmission or Direct Drive
Size-APU		
11 Cubic Ft. Max.	11 Cubic Feet	4 Cubic Feet
Size-Accessory Drive and Accessories		
9.5 Cubic Feet	9.5 Cubic Feet	9.5 Cubic Feet
Maximize Accessibility	Access Door Provided Top and Front. Replacement Requires Powerpack Removal	Consider Redesign
Enhance Cold Start Capability	APU Operation	APU Operation
Minimize Weight	APU - 240 Lbs. Vehicle Accessory Gearbox 200 Lbs.	Minimize Weight

5.2.4 Cooling and Exhaust System. The powerpack cooling system is mounted on the transmission (Figure 5-33). The cooling system includes identical sets of fans, diffusers, fan drives, coolers, and a cooler duct, sealing, oil supply and return lines. The mechanically driven fans provide airflow to meet powertrain cooling requirements. The system uses existing fan technology.

The exhaust system provides ducting for the main engine, scavenge blower, and APU exhaust directing it to the right rear vehicle grilles.

5.2.4.1 Goals. The following are the goals of the cooling and exhaust systems for the engine and transmission:

Parameter	Goal
System	Provide a mechanically driven cooling system

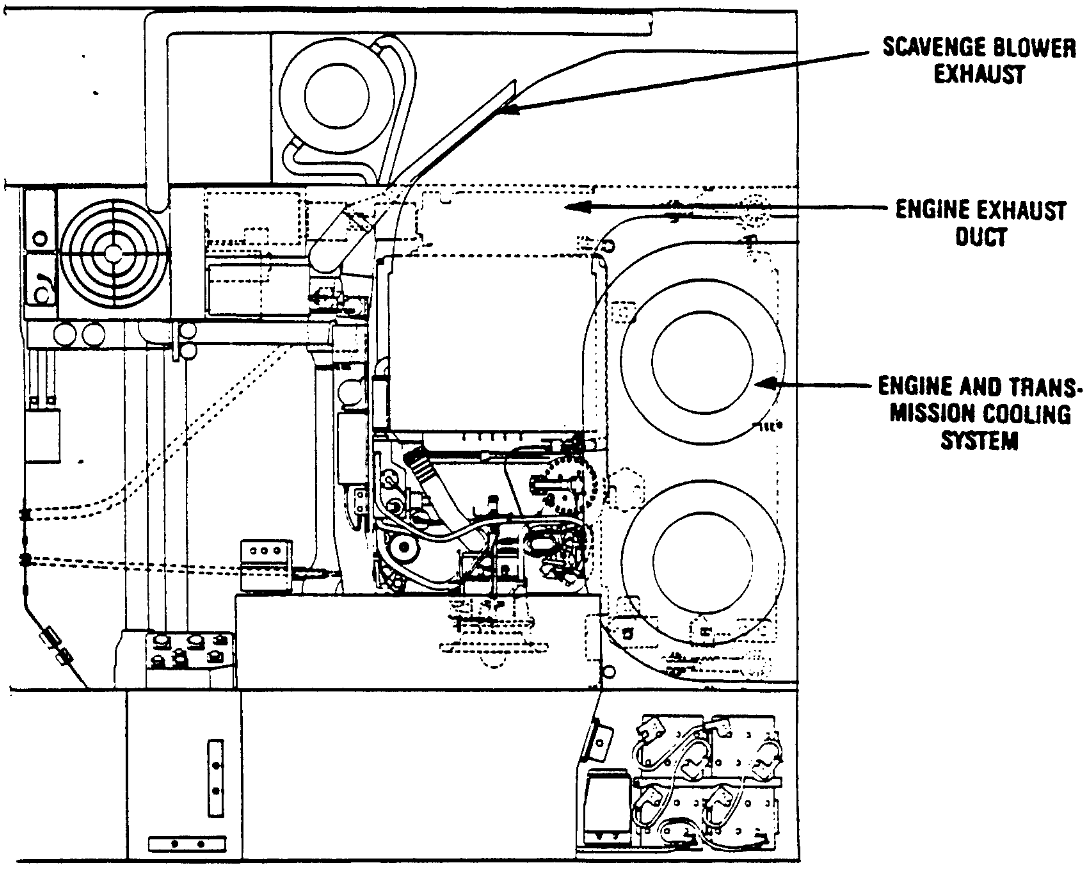


Figure 5-33. Cooling and Exhaust System

Parameter	Goal
Powertrain Cooling	Transmission oil at or below 265°F sump and 315°F cooler inlet temperatures, and engine oil at or below 325°F at cooler inlet for 125°F ambient at tractive effort of .67/.70 NBC on/off
Accessibility	Improved over M1A1
Environmental	Same as M1A1 (System Specification)
Weight	Equal to or less than M1A1
Exhaust	Minimize recirculation
Water Fording	Accommodate vehicle fording up to 48 inches of water without kits.

5.2.4.2 Technical Approach.

Cooling System

The design guidelines for cooling the engine and transmission were:

- o Mount cooling system on powerpack
- o Provide access for transmission oil filters
- o Provide removable Foreign Object Damage (FOD) screen
- o Provide adequate inlet grille area for each fan
- o Provide a system capable of rejecting 10,111 BTU/min from transmission oil
- o Provide a system capable of rejecting 3500 BTU/min from engine oil
- o Provide engine compartment air circulation
- o Provide engine and transmission cooling margin

Exhaust System

The design guidelines for the exhaust of the main engine, scavenge blower and APU were:

- o Must have a quick disconnect for APU exhaust

- o Restriction of exhaust back pressure no greater than M1A1/M1

- o Use currrent duct mounting design to engine with revised access

- o Provide sealing for vertical integrated powerpack removal/installation

- o No hot air exhaust will be routed to the top deck

- o Provide for scavenge blower exhaust route

5.2.4.3 Design Analysis. The cooling system removes heat from the engine and transmission lubricating oil with two ring type coolers. The coolers transfer the heat to the cooling air which is pulled in through the top deck, routed radially from the fans through the coolers and exhausted to the rear of the tank.

The exhaust system accepts the exhaust flow from the main engine, and APU. The system uses the current M1A1 smoke generating hardware.

Cooling System

The cooling fans are designed to meet the powerpack cooling space allotment and performance requirements. Both fans together are capable of flowing a total of 15,152 cfm of air (density 0.066 pounds per cubic feet) at 14 inches of water static pressure through the cooling system. A performance assessment of a single fan at 9,000 and 10,000 rpm (air density 0.066) is shown in Figure 5-34. The fans selected will require a total maximum of 76.8 HP for top speed operations. The annular heat exchanger assemblies will be capable of cooling the powerpack oil at the maximum vehicle speed and when the vehicle tractive effort is 70% of the gross vehicle weight (GVW) in ambient air temperatures of up to 125°F.

The cooling point for the ATR is at the maximum vehicle speed. A single cooler assembly performance assessment was made and consists of the following:

- o Heat Rejection versus Airflow, Figure 5-35.

- o Air Pressure Loss versus Airflow, Figure 5-36.

- o Oil Pressure Loss versus Oilflow, Figure 5-37.

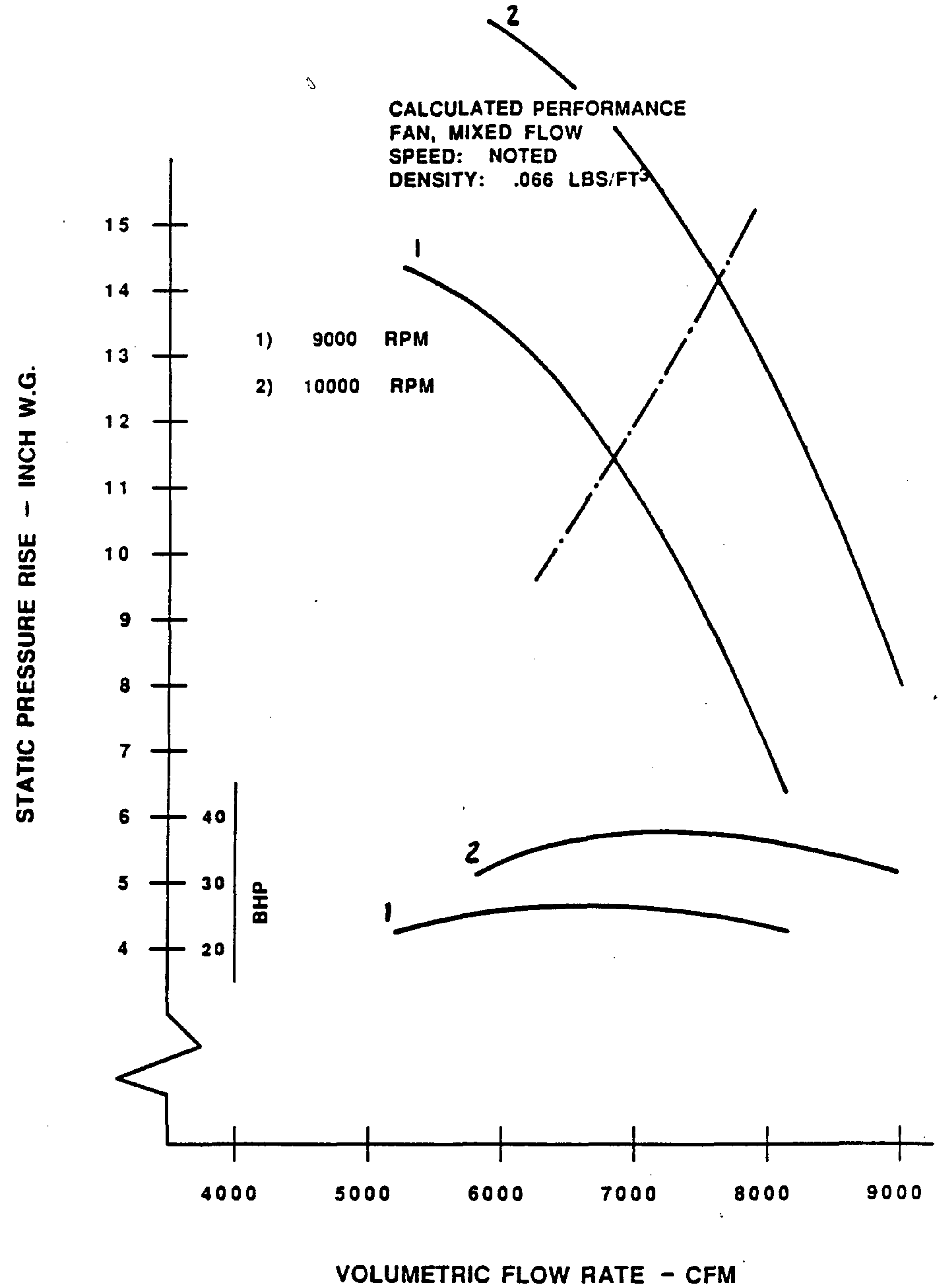


Figure 5-34. Single Fan Performance - Static Pressure vs Flow Rate

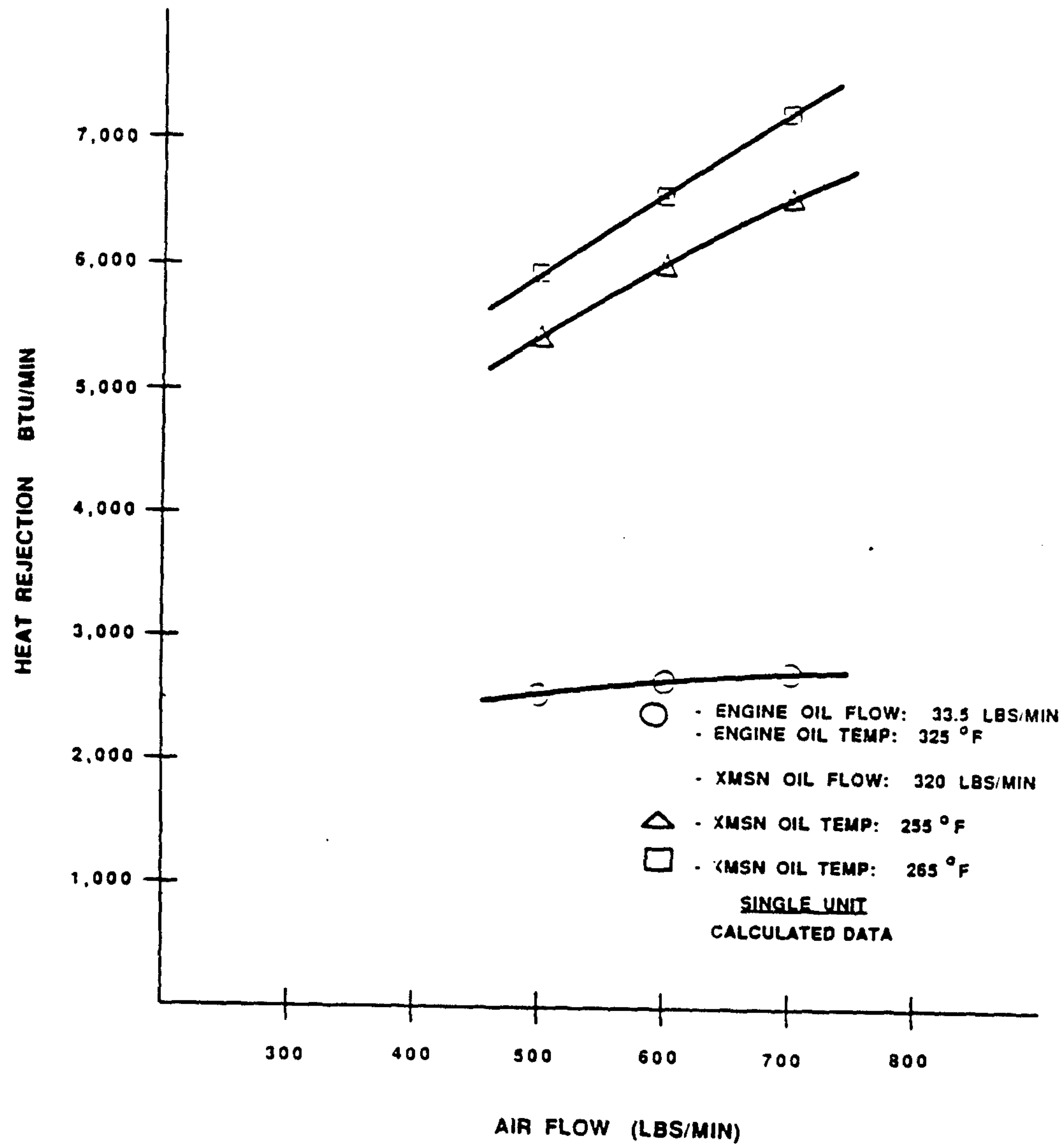


Figure 5-35. Single Fan Cooler - Heat Rejection vs Airflow

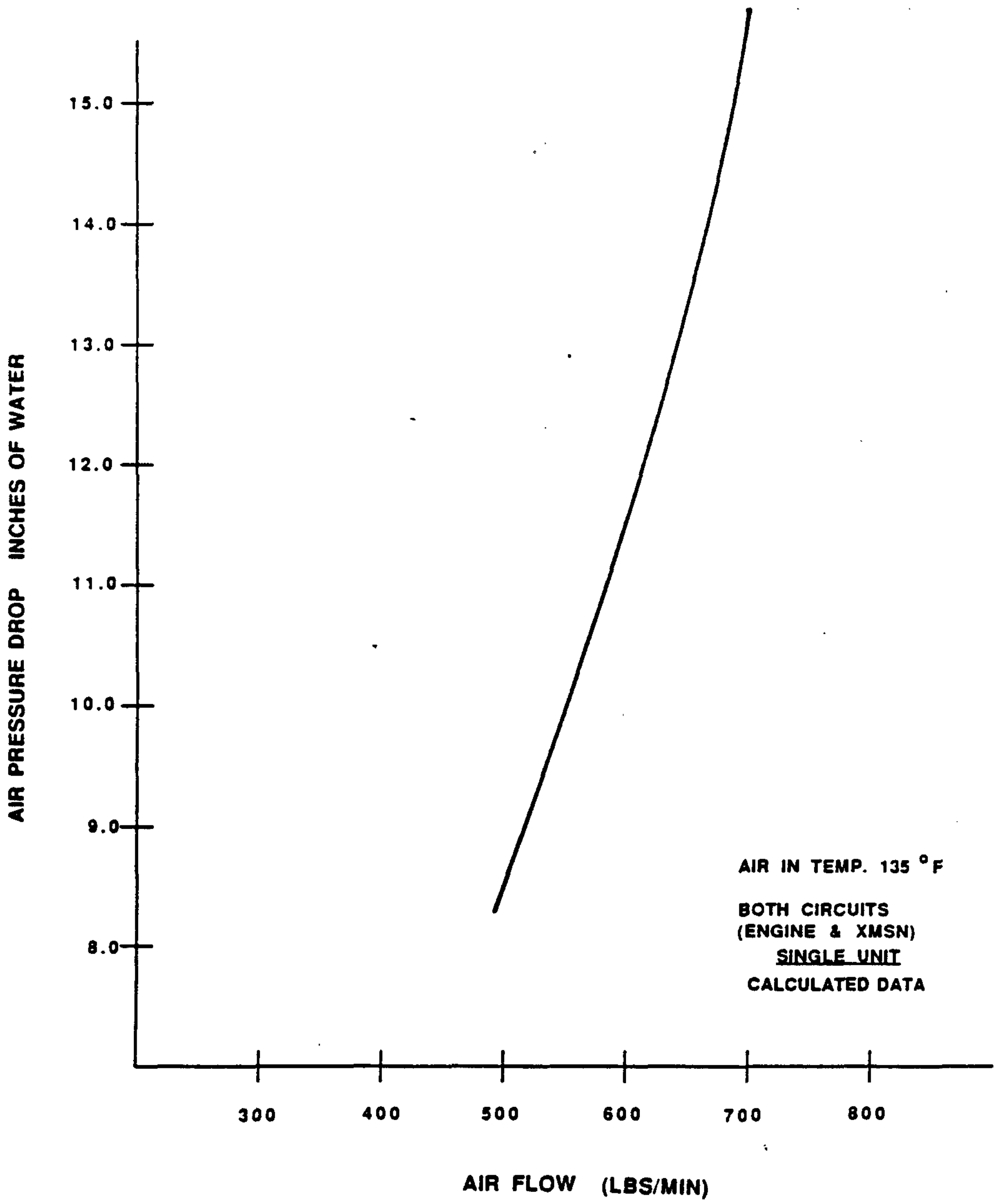


Figure 5-36. Single Fan Cooler - Air Pressure Loss vs Airflow

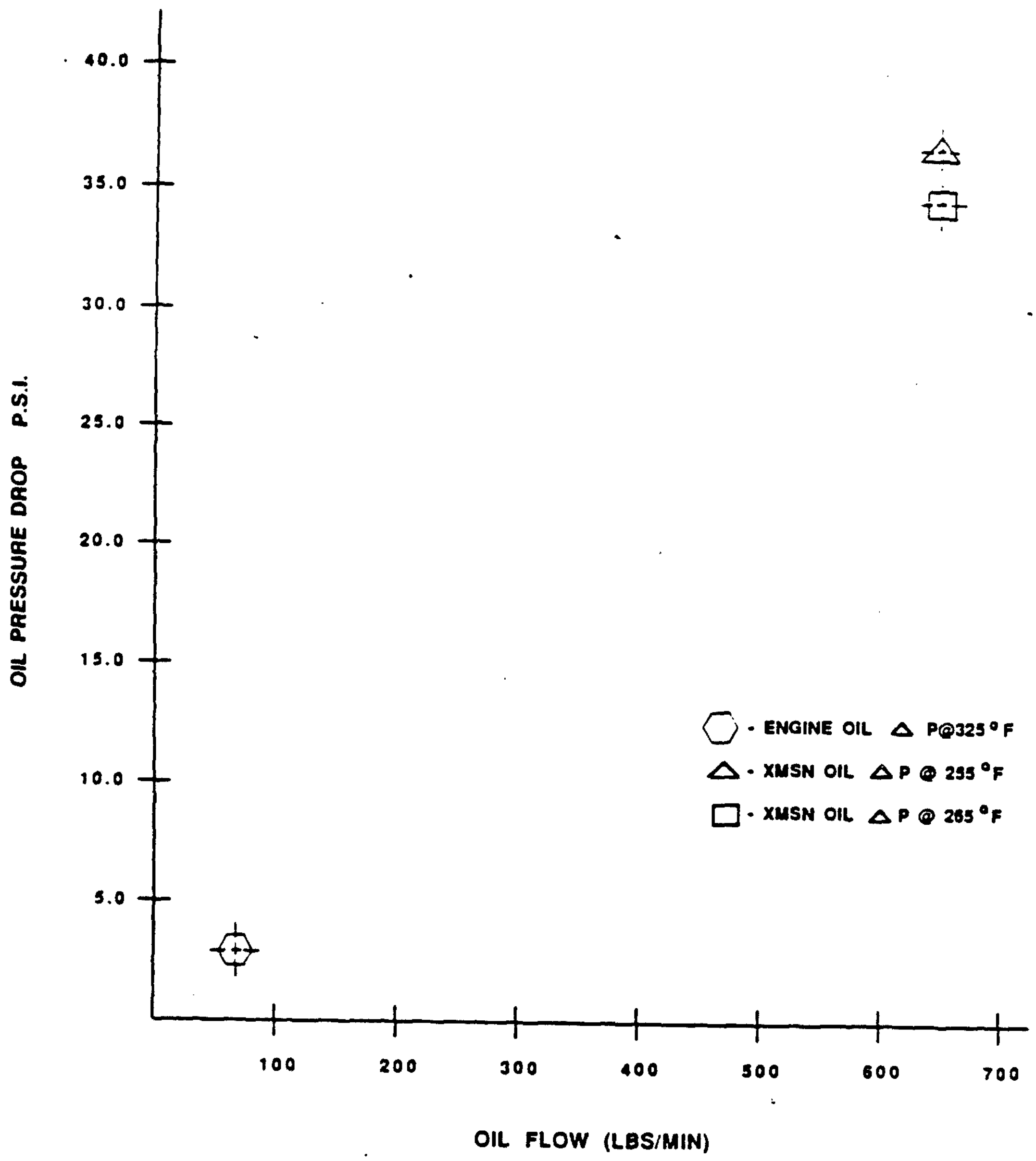


Figure 5-37. Single Fan Cooler - Oil Pressure Loss vs Oil Flow

The estimated flow, velocity, and static pressure losses at various flowpath stations within the cooling system were graphically summarized, Figure 5-38. In addition, the powerpack inlet and outlet temperatures and airflow areas were also analyzed.

An airside fin comparison study was made for selecting cooling fin type and fins per inch spacing. This study compares louvered fin designs used on M1/M1A1 with the TMEPS selected perforated straight fins for flow, heat transfer area, pressure loss and heat rejection capabilities. This data supported selection of the perforated straight fin configuration and spacing that meets powerpack cooling requirements, including 10-15 percent margin. The selected straight fin configuration is less susceptible to clogging and easier to clean than the M1A1 louvered fin coolers.

The straight perforated fin, aligned and spaced at 20 fins per inch (FPI) throughout the core, meets the heat transfer, pressure loss and environmental requirements. The cooler straight fin spacing (20 FPI) compares favorably with the effective fin spacing of the M1A1 fin coolers at 17, 20, and 27 FPI for the primary, auxiliary, and engine coolers, respectively. The fin data summary is shown in Table 5-3.

Comparison data was collected for the cooling fan inlet and inlet grille areas for the M1A1 and TMEPS (Table 5-4). A comparison was also made for the induction, cooling and exhaust system (Table 5-5). These comparisons were used as design guides.

Exhaust System

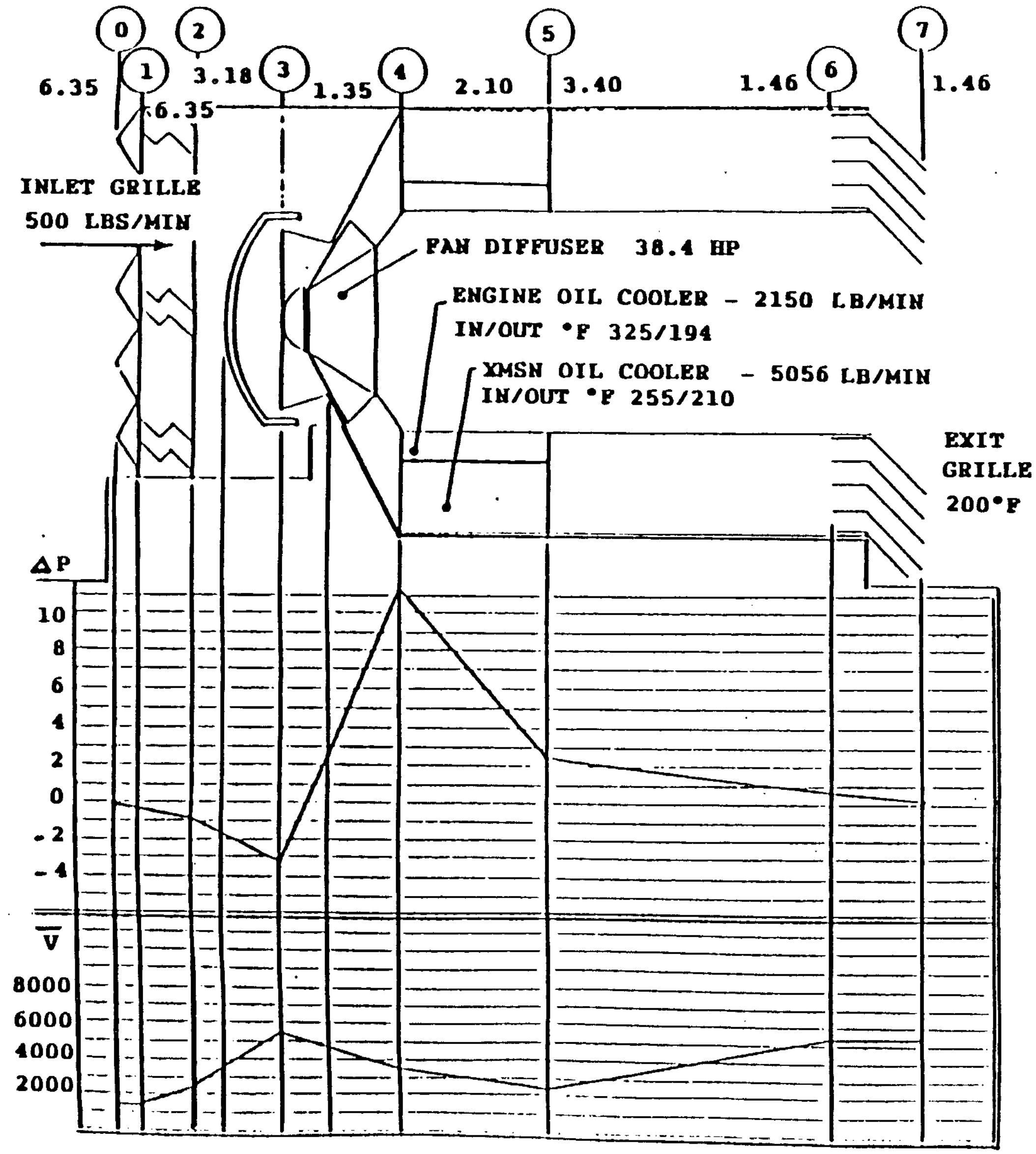
A graphic analysis was made to determine the optimum mounting bolt access arrangement. From the analysis, it was concluded that the exhaust duct should have an access panel in the upper skin and that the fasteners at the interior should be safety wired to prevent loosening and potential accidental recuperator damage.

The analysis also indicated that the duct could be supported at the hull by a seal and retainer configuration shown on Figure 5-39.

5.2.4.4. Tradeoffs.

Cooling System

The cooling system trade-off analysis showed that because of the limited available space betweeen powerpack and hull, a conventional system, including fan/transition duct/slab cooler,



STA		ΔP	RHO
0	SCREEN FACE		.068
1	GRILLE FACE	-.09	.066
2	GRILLE EXIT	-.48	.066
3	FAN ENTRY	-2.59	.066
4	CORE FACE	+14.2	.066
5	CORE EXIT	-8.5	.059
6	GRILLE FACE	-1.74	.059
7	GRILLE EXIT	-.24 +.56	.059

STA		A FT^2	$\bar{V}$ FT/MIN
0	SCREEN FACE	6.35	1193
1	GRILLE FACE	6.35	1193
2	GRILLE EXIT	3.18	2386
3	FAN ENTRY	1.35	5611
4	CORE FACE	2.10	3607
5	CORE EXIT	3.40	2492
6	GRILLE FACE	1.46	5800
7	GRILLE EXIT	1.46	5800

Figure 5-38. Cooling System Flowpath

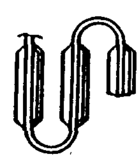
Table 5-3. Air Side Fin Comparison

TMEPS

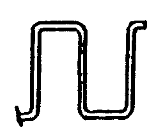
	FIN CONFIGURATION	FREE FLOW AREA FT^2	SURFACE AREA FT^2	ΔP AIR	HEAT REJECTION B/MIN	EFFECTIVE FIN SPACING - FPI
XMSN	PLAIN, PERFORATED, .375 H, .008 TH, 20 FPI	.144	37.104	21.09 IWG	442.19	20
ENGINE	SAME AS TRANSMISSION	SAME AS TRANS-MISSION	SAME AS TRANS-MISSION	SAME AS TRANS-MISSION	SAME AS TRANSMISSION	20

M1A1

	FIN CONFIGURATION	FREE FLOW AREA FT^2	SURFACE AREA FT^2	ΔP AIR	HEAT REJECTION B/MIN	EFFECTIVE FIN SPACING - FPI
PRIM. XMSN	LOUVERED, .375 H, .006 TH, 10 FPI	.162	21.002	27.4 IWG	434.34	17
AUX. XMSN	LOUVERED, .375 H, .006 TH, 12 FPI	.160	24.295	33.7 IWG	442.49	20
ENGINE	LOUVERED, .375 H, .006 TH, 16 FPI	.156	30.881	48.8 IWG	453.72	27



LOUVERED FIN



PERFORATED FIN

Table 5-4. Grille and Cooling Fan Area

CONFIGURATION	RIGHT SIDE GROSS GRILLE AREA	RIGHT SIDE FAN INLET AREA UNDER GRILLE	LEFT SIDE GROSS GRILLE AREA	LEFT SIDE FAN INLET AREA UNDER GRILLE
M1A1	3.52 SQ. FT.	2.89 SQ. FT.	3.38 SQ. FT.	3.30 SQ. FT.
TMEPS	6.35 SQ. FT.	6.00 SQ. FT.	6.35 SQ. FT.	6.00 SQ. FT.

Table 5-5. Induction - Exhaust Cooling TMEPS/M1A1

INDUCTION		EXHAUST		COOLING	
M1A1	**TMEPS**	**M1A1**	**TMEPS**	**M1A1**	**TMEPS**
System Descriptions:					
Passive dual stage cleaner with scavenge blower.	Self cleaning dual stage cleaner with scavenge blower	Insulated steel duct.	Insulated steel duct.	Oil to Air plate-fin slab coolers with transition duct & vaneaxial fan.	Oil to Air plate-fin ring coolers with mixed flow fans.
Suppliers:					
Donaldson Inc./ PLM Inc.	Textron Inc.	GDLS Inc.	GDLS Inc.	Noah Inc. Able Inc. Stewart- Warner Inc.	Noah Inc. Stewart- Warner Inc.
System Weight:					
434 lbs.	335 lbs.	285 lbs.	394lbs.	727lbs.	375 lbs.
Size:					
38.7 ft^3	29.6ft^3	9.7ft^3	13.6ft^3	15ft^3	9ft^3
Characteristics:					
(1) Inertial Separator (3) Barrier Filters (1) Mech. driv. Scav. blower	(1) Inertial Separator (1) Rotating Barrier filter (1) Air Compressor with Backflow & Suction nozzle (1) Mech. driv. Scav. blower	One inch thick Ceramic fiber insulation. Aluminized Steel structure.	One inch thick Ceramic fiber insulation. Aluminized Steel structure.	(2) 3700 rpm Vane ax. fans 7500cfm each (3) 6in thick alum. plate -fin slab coolers. fan dia =16in. system ΔP= 11 Iwg Hp/ fan =21(.066)	(2) 10,000 rpm mixed flow fans. 7575 cfm each/ (2) 5in thick alum. plate fin ring coolers. fan dia =12in system Δp = 14.2 Hp/ fan =38.4 (.066)
Performance:					
22.5 IWG Δp clean @ 10,000 cfm 99.8% efficient. 20 hrs @ zero visibility	Same as M1A1 Except 200 hours @ Zero Visibility	6IWG ΔP @ 10,000 cfm. Internal temp. 970°F external temp 250°F.	Same as M1A1	Engine 4,300 b/min @ 325°F oil to cooler. xmsn 14000 b/min @ 265°F oil to cooler.	Engine 4,300 b/min @ 325°F oil to cooler. margin =16% xmsn 10,111. b/min @ 265°F oil to cooler. margin =17.7% @ 255° F oil to cooler margin = 9.4%

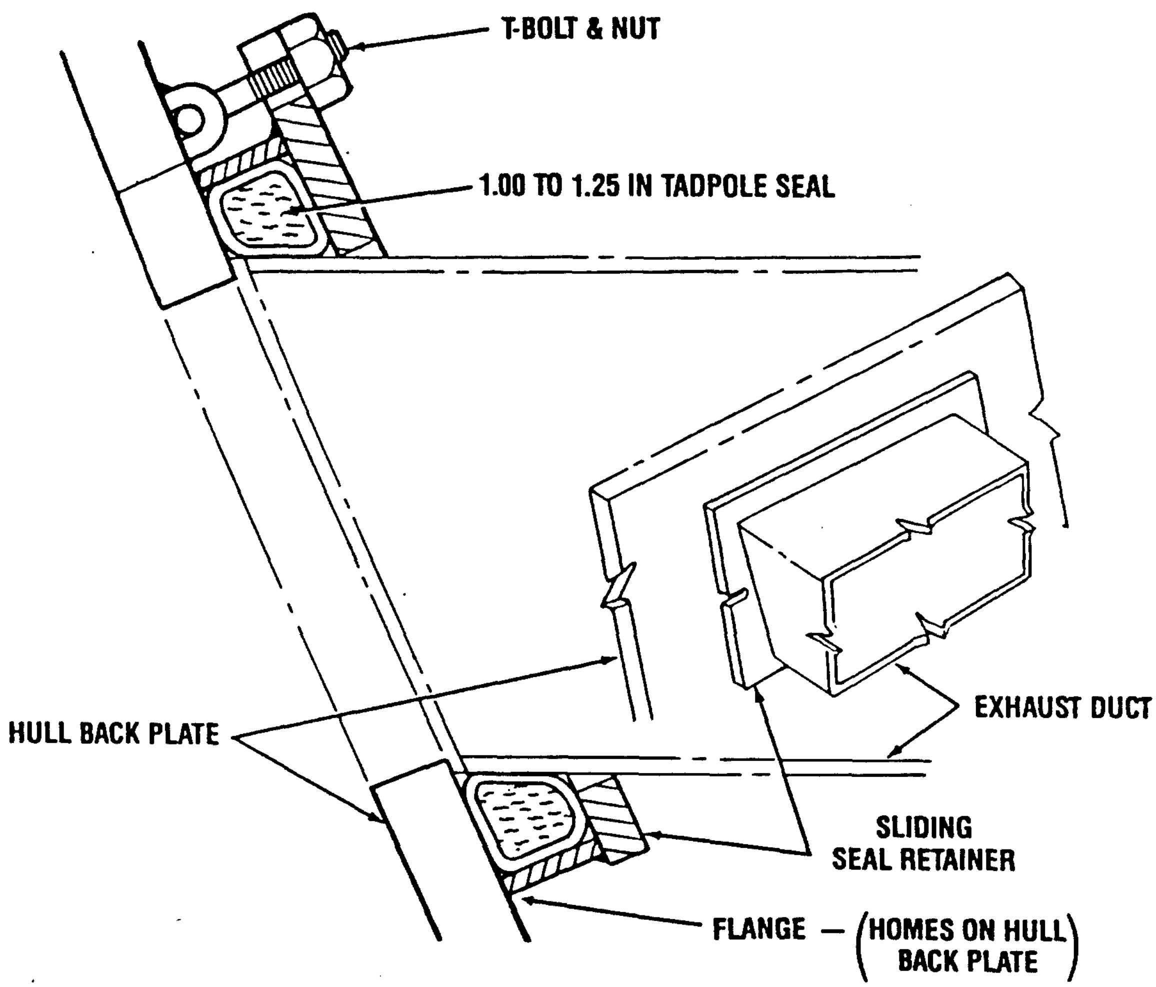


Figure 5-39. Seal/Retainer Configuration

would exhibit interference. In addition, more than two fans would be required.

The use of two identical ring-coolers with integral fan/diffuser assemblies, on the other hand, provided a cooling package that could be accommodated in the space available and could be mechanically driven.

Exhaust System

There were two options for exhaust duct routing. One approach exits the exhaust at the rear of the vehicle and the other directs exhaust over the vehicle left or right side. Since exiting over the side would significantly alter the IR signature, the rear exhaust as selected.

5.2.4.5 Selected Design. For reasons given in Section 5.2.4.4., the selected cooling system consists of integral fan/diffuser/cooler assemblies, transmission PTO driven. These fans take air through an intake grille in the top deck, disperse the air through an annular diffuser into an annular cooler and exit through a collector duct and ballistic grille at the vehicle rear.

The selected exhaust duct concept routes exhaust gas to a vehicle rear exit. The construction is similar to M1/M1A1, and the shape is basically driven by powertrain component packaging.

The engine/transmission cooling and exhaust system goals and compliances are:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURES)
Powertrain Cooling:		
Transmission at or Below 265°F Sump Temperature and 315°F Cooler Inlet. Engine at or Below 325°F at Cooler Inlet for 125°F ambient at Tractive Effort of .67/.70 NBCC ON/OFF	Transmission at 255°F Cooler Inlet. Engine at or Below 325°F. Cooler Inlet for 125°F Ambient and Max. Vehicle Speed	Same as ATR
Provide a Mechanically Driven Cooling System	Provided	Same as ATR

GOAL	ATR-TMEPS	M1-TMEPS (FUTURES)
Accessibility Improved over M1A1	Improved Accessibility Over M1A1	Same as ATR
Environmental-Same as M1A1	Environment-Same as M1A1	Same as M1A1
Weight-Equal to or Less Than M1A1	Weight Less Than M1A1	Same as ATR
EXHAUST:		
Minimize Recirculation	No Hot Air Exhaust Through Top Deck	Same as ATR
Accommodate Fording up to 48" Without Kits	Accommodate Fording up to 48" Without Kits	Same as ATR

5.2.5 Hyraulic System. The ATR hydraulic system is similar to the M1A1 system (Figure 5-40). It includes the following (Figure 5-41):

- o Hull/Turret Drive System
  - Hydraulic pump
  - Hydraulic reservoir assembly
- o Accessory Cooler and Fan Drive

5.2.5.1 Goals. Goals for the Hull/Turret drive system and accessory cooler fan drive system are as follows:

Hull/Turret Drive System

PARAMETER	GOALS
o Hydraulic Fluid/flow	Same as M1A1 Fluid MIL-H-46170, 1650 $\pm$ 50 PSI, 27 GPM at Idle
o Environmental	Same as M1A1
o Weight	Minimize Weight Increase
o Safety	Reduce Potential for Leaks

Accessory Cooler and Fan Drive

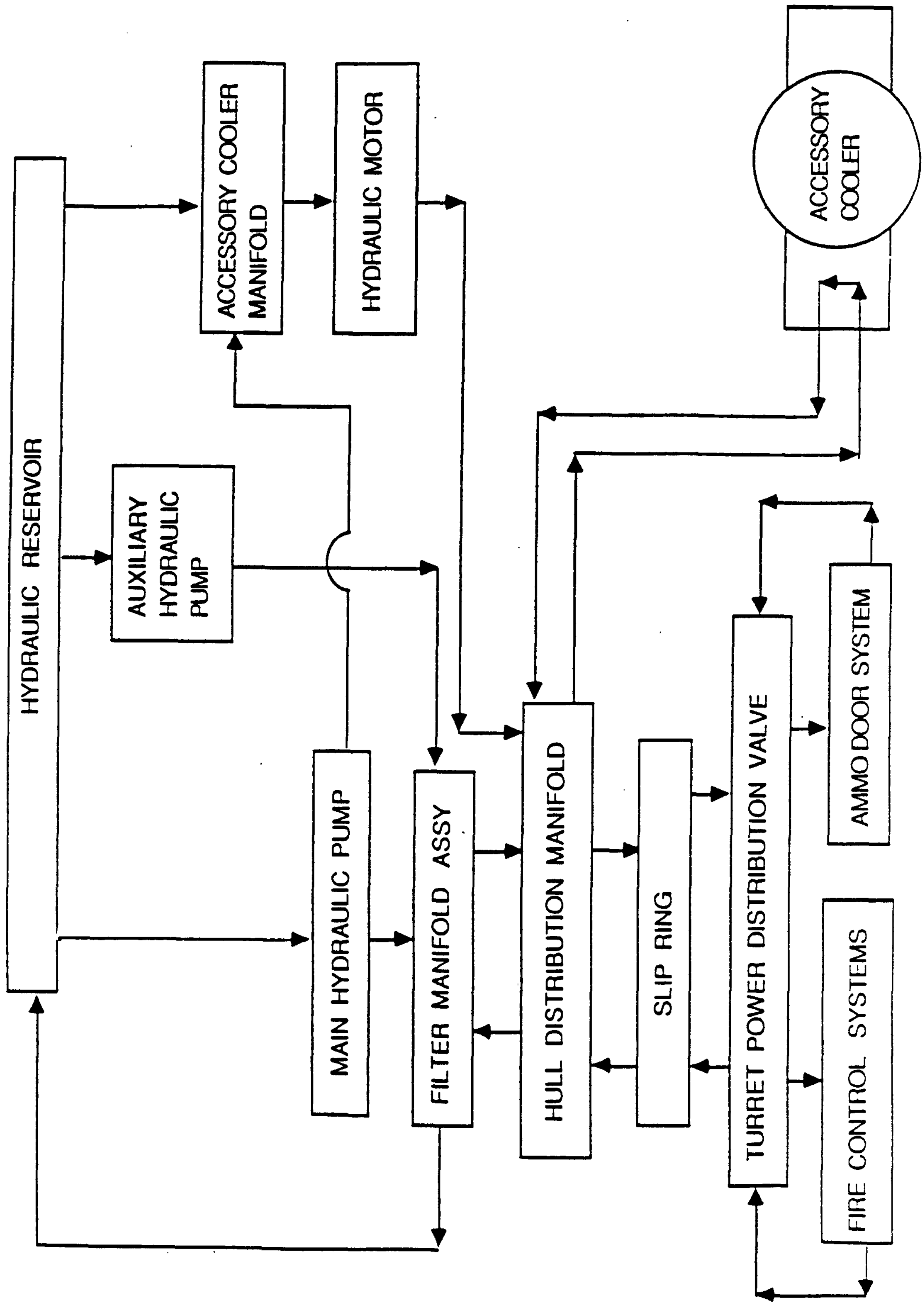


Figure 5-40. TMEPS Hydraulic System Block Diagram

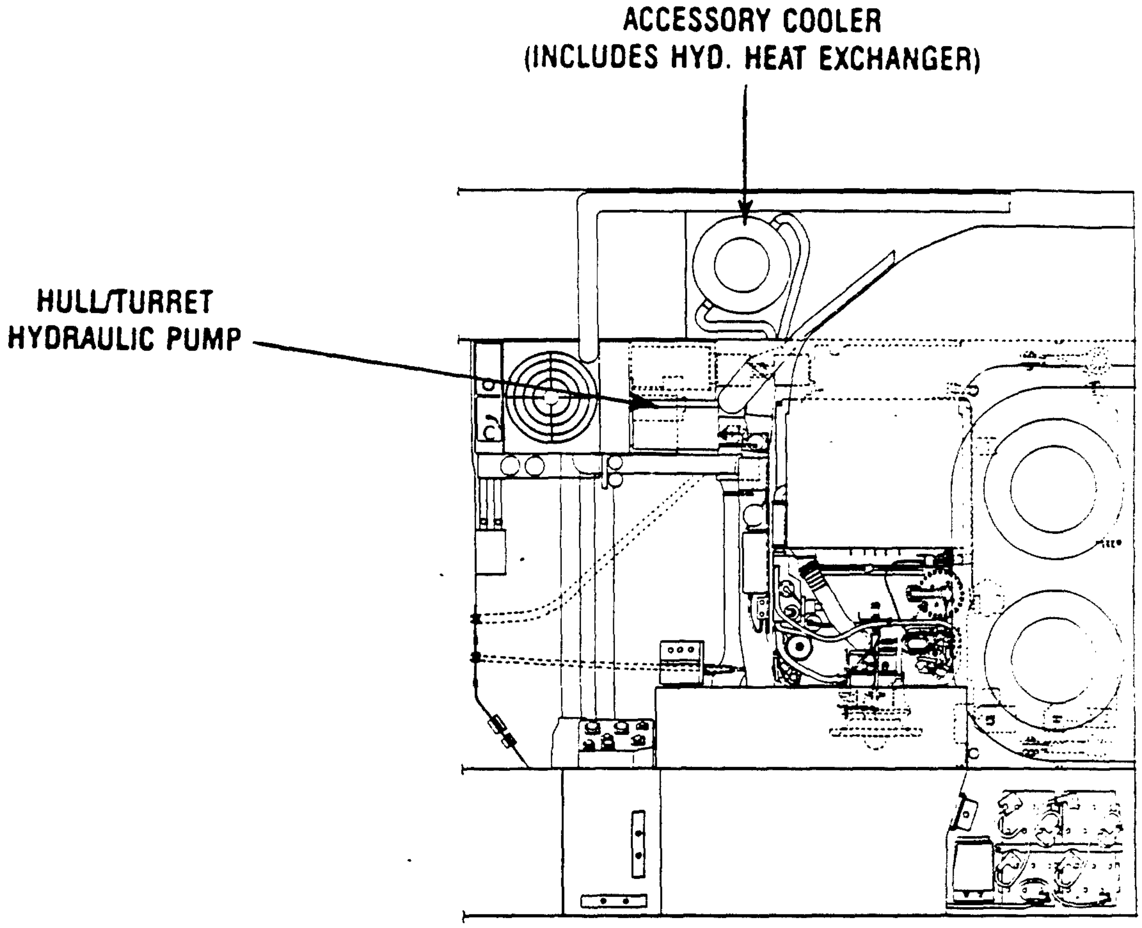


Figure 5-41. Hull/Turret Drive System

PARAMETER	GOALS
o Cooling	2120 BTU/min heat rejection
o Airflow	Sufficient to provide required cooling
o Fluid	MIL-H-46170 and Santo Trac 50
o Environmental	Same as M1A1
o Weight	Minimize weight increase
o Safety	Same as M1A1

5.2.5.2 Technical Approach:

Hull/Turret Drive System

The main hydraulic pump (same as M1A1) is driven from the VAG at a constant speed of 3750 rpm. On the M1A1 engine accessory gearbox, the main hydraulic pump is dependent on the engine compressor speed. The hydraulic pump will provide a flow of 33 gpm at a discharge pressure of 1600 psi. The hydraulic reservoir assembly was modified and relocated from the left side of the vehicle to the right side.

The design guidelines for the hydraulic hull/turret drive system were:

- Provide equivalent (to M1A1) power for the hydraulic hull/turret drive system.
- Ensure retention of current main hydraulic pump.
- Eliminate quick-disconnects to reduce potential for fire hazards.
- Provide improved fittings to eliminate or significantly reduce fitting leakage.

Accessory Cooler and Fan Drive System (Figure 5-42).

The accessory cooler hydraulic motor is used to power the cooling fan which reduces the vehicle accessory gearbox and accessories oil temperature. It will only provide cooling when the main engine is in operation. The CVT/APU control valve diverts oil flow from the accessory cooler to the APU heat exchanger to cool the oil when the main engine is not running. The design guidelines for the accessory cooler and fan drive systems:

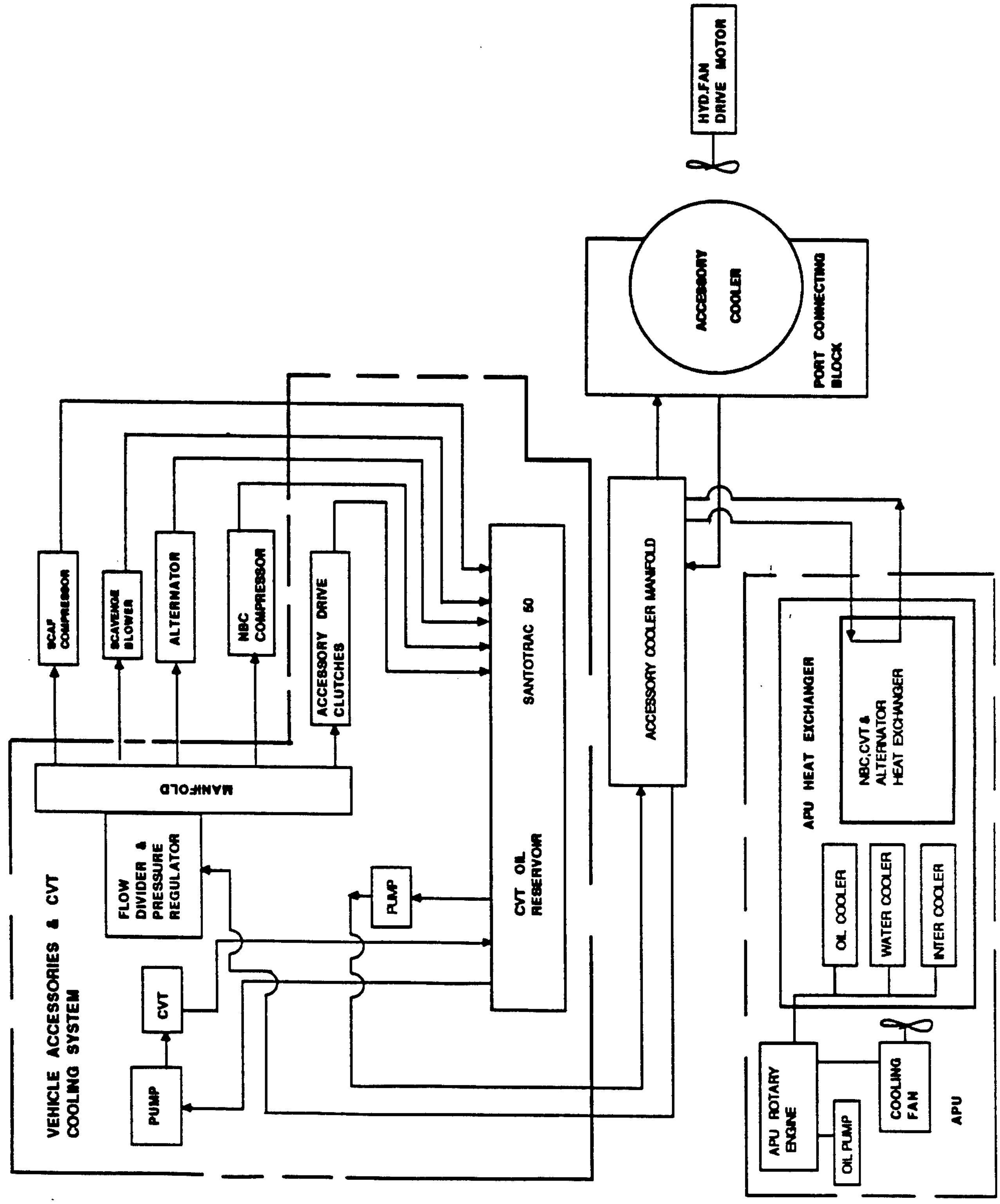


Figure 5-42. Accessory Cooler and Fan Drive System Flow Block Diagram

- Provide 200 BTU/min cooling for hull/turret drive hydraulic system
- Provide 1,900 BTU/min cooling for CVT/accessories
- Provide necessary fan horsepower to meet cooling requirements
- Provide combined heat exchanger for hydraulic and vehicle accessory gearbox oil to minimize space claim
- Locate to optimize airflow for cooling fan
- Reduce fluid leakage by using improved fittings

5.2.5.3 Design Analysis. The hydraulic system analyses conducted were:

- Hull/Turret Pump Size Analysis
  - Flow at Different Speeds

    The current M1A1 pump operates through a variable range from 3000 to 5000 rpm with a flow of 28 to 47 gpm, respectively. Analysis was conducted to select an optimum constant speed for TMEPS pump operation. The TMEPS pump operates at a constant speed of 3750 rpm providing a flow of 35.7 gpm which meets vehicle maximum flow requirements.

  - Main Pump Suction Pressure Drop at Different Temperatures

    The main pump is relocated approximately 10 feet from the current M1A1 main reservoir. An analysis was made to determine the location affect on cavitation. The analysis indicated that a safe condition is realized for all line sizes and ambient temperature ranges of the hydraulic oil, if the reservoir was relocated to the right side of the vehicle, behind the main bulkhead.

5.2.5.4 Tradeoffs.

Hull/Turret System

The Hull/Turret system design alternatives evaluated were:

- Face Seal Fittings versus MS Flareless Fittings

Characteristics

Face Seal	MS Flareless Fittings
o No distortion of sealing surface due to excessive torque	o Could distort due to excessive torque
o Sharp torque rise indi- cates proper torque limit	o No clear indication of over torquing
o Soft seal - readily adapts to surface damage	o Metal to metal seal - not adaptable to surface damage
o Hand tight fitting will not readily leak	o Needs precise torque to avoid leaking
o Operating pressure from vacuum to 6000 psi	o Operating pressure - up to 3000 psi
o Vibration resistance - excellent	o Vibration resistance - very good
o Assembly and disasembly - no springing of asso- ciated tubing for clearance	o Assembly and disassembly - needs springing

Face seal fittings were selected over MS flareless fittings for incorporation into the design.

o Heat Exchanger - Combined versus Separate

The following characteristics comparison was made:

One Combined Heat Exchanger	Separate Heat Exchangers
o One cooler replaces two separate coolers	o Needs two separate coolers
o Needs one fan for both coolers	o Needs one fan for each cooler
o Needs one fan drive	o Needs one fan drive for each fan
o Small size allows it to be located in sponson for optimum air intake and exhaust	o Cannot be located in sponson for optimum air intake and exhaust due to large space requirement
o Design allows more space in the engine compartment	o Design will reduce available space in the engine compartment
o Low weight	o Weighs more
o Less complex than separate cooler system	o More complex system due to extra line routing, transition ducts, two fans

One combined heat exchanger is integrated into the design.

Accessory cooler and Fan Drive

The accessory cooler and fan drive alternative designs evaluated were:

- o Ring Cooler versus Slab Cooler

Characteristics

Ring Cooler	Slab Cooler
o One cooler replaces two coolers	o Needs two separate coolers
o Needs one fan drive	o Needs two fans
o Small size allows it to be located in sponson for optimum air intake and exhaust	o Can not be located in sponson for optimum air intake and exhaust due to its large size
o Design allows more space in the engine compartment	o Design will reduce available space in the engine compartment
o Requires less space	o Requires more space
o Weighs less	o Weighs more
o Less complex system	o More complex system due to extra line routing
o Higher cost due to higher initial development cost	o Lower cost due to off-the-shelf hardware

A ring cooler was selected for the TMEPS design.

o Hydraulic versus Mechanical Drive for Auxiliary Cooling Fan

Characteristics

Hydraulic Drive	Mechanical Drive
o Easier to locate in the sponson for optimum air intake and exhaust	o Very difficult to provide mechanical drive in the sponson with pulleys, belts or gears
o Relatively more compact	o Requires more space to provide fan drive in the sponson
o Provide flexibility to locate some of the components away from the sponson	o Most of the components must be located in the vicinity of the sponson, where it is difficult to find more space
o Design allows more space in the engine compartment	o Design will reduce available space in the engine compartment
o Requires less space	o Requires more space
o Weighs less	o Weighs more
o Less complex system	o More complex system due to compicated pulleys and gearing arrangements
o Lower cost	o Higher cost due to extremely complex arrangement

Hydraulic drive for the cooling fan was selected.

- o Hydraulic versus Electrical Drive for Auxiliary Cooling Fan

Characteristics

Hydraulic Drive	Electric Drive
o Sufficient power is available to drive the fan	o Sufficient power is not available to drive the fan
o Relatively more compact and it saves space	o Requires large size 24 volt motor to drive the cooling fan
o Can be located in the sponson for optimum air intake and exhaust position	o Cannot be located in the sponson due to large motor size. This requires complicated ducting for air intake and exhaust
o Design allows more space in the engine compartment	o Design will reduce available space in the engine compartment
o Weighs less	o Weighs more

- o Rear Cooling Air Exhaust vs. Top Deck Cooling Air Exhaust

Characteristics

Rear Cooling Air Exhaust	Top Deck Cooling Air Exhaust
o Minimum impact on vehicle heat signature	o Relatively larger impact on heat signature
o Open cavity in sponson forms a natural duct	o Ducting required
o Saves space	o Needs space for the duct
o Low weight	o Weighs more
o Less complex system due to low number of parts	o More complex system due to extra duct routing
o Low cost due to low number of parts	o Higher cost due to more parts

A rear cooling air exhaust route was selected.

5.2.5.5 Selected Design. The hydraulic hull/turret drive and accessory cooler fan drive systems selected concepts are:

- o Production Hull/Turret Pump (Constant Speed 3750 ± 100 RPM)
- o Elimination of Quick Disconnects wherever possible
- o Use of Face Seal Fittings
- o Pump Mounted on Vehicle Accessory Gearbox (VAG)
- o No plumbing Separation Required During Powerpack Removal
- o Combined Annular Hydraulic Fluid Cooler/Accessory Cooler
- o Relocated Hydraulic Reservoir for Reduced Low Temperature Cavitation Susceptibility
- o Constant Speed Fan Drive Hydraulic Motor 1650 ± 50 PSI, Pressure, 7 GPM Flow
- o Rear Exit Exhaust

The Hull/Turret Drive System Compliances Are:

GOALS	ATR-TMEPS	M1-TMEPS (FUTURE)
System Performance	Hydraulic System 1650 ± 50 PSI	Same as ATR
Hydraulic System 1650 ± 50 PSI		
Environment		
Same as M1A1	Same as M1A1	Same as ATR
Weight		
Minimize Wt. Increase	35 Lb Increase	Same as ATR
Safety		
Same as M1A1	Eliminated Quick Disconnects and Reduced Potential for Leaks	Same as ATR

The Accessory Cooler and Fan Drive System Compliances Are:

GOALS	PARAMETERS	M1-TMEPS (FUTURE)
System Performance	Hydraulic System 1650 ± 50 PSI	Same as ATR
Hydraulic System 1650 ± 50 PSI		
Heat Rejection 2800 BTU/min	Meets	Same as ATR
Environment		
Same as M1A1	Same as M1A1	Same as M1A1
Weight		
Minimize Wt. Increase	20-lb Increase	Same as ATR
Safety		
Same as M1A1	Reduce Potential for Leaks	Same as ATR

5.2.6 Fuel System. The propulsion system incorporates a reconfigured fuel conditioning system which performs the same functions as the M1A1 system. The APU has its own integral fuel conditioning system. The ATR fuel system (Figure 5-43) provides fuel to the APU, the main engine, and the smoke generator system from the front M1A1 fuel tanks. For the ATR, the M1A1 engine compartment and sponson fuel tanks, with their respective pumps and fuel level sensors, are removed.

Two fuel pumps were located under the turret basket. One pump supplied fuel to the APU, the other supplied fuel to the main engine and smoke generator system.

5.2.6.1 Goals. The design goals for the fuel system were:

PARAMETER	GOALS
*Range	
NBC ON	279 Miles Nominal
NBC OFF	289 Miles Nominal
*Vehicle Fuel Capacity	473 Gallons Minimum (255 Gallons ATR Only)

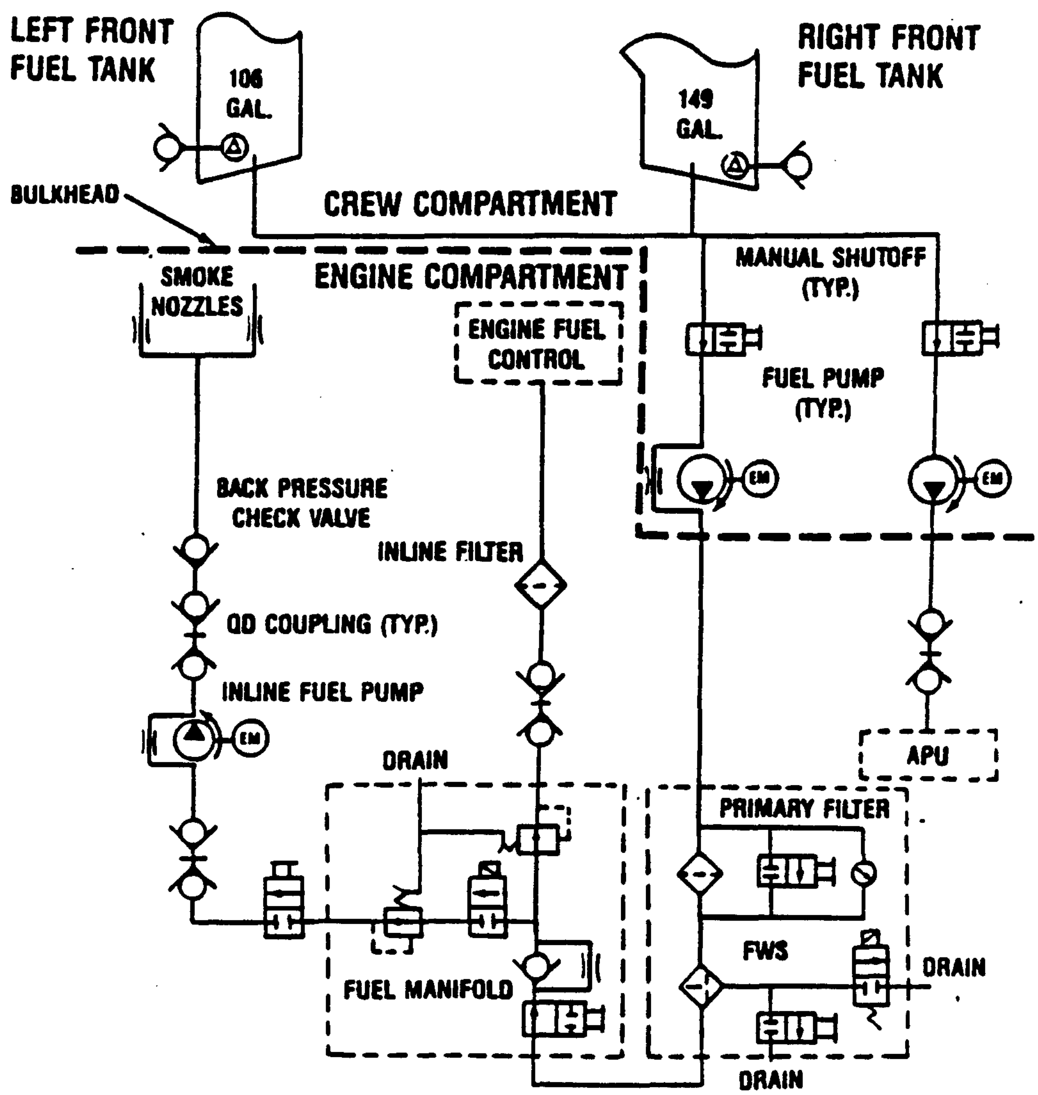


Figure 5-43. TMEPS Fuel System

PARAMETER	GOALS
*Under Armor Capacity	78% Based on Fuel for 289 Mile Range
Fuel Types	Same as M1A1
Emergency Operation	Provide Manual Shut-Off Same as M1A1
*Starting Attitude	60% Longitudinal 40% Side Slope Same as M1A1
Starting Temperature	-25°F to 125°F Without Kit: Down to -65° With Kit
Environmental	Same as M1A1
Weight	Reduce

*NOTE: To the nature of the ATR peculiar design, the ATR does not meet these M1A1 requirements. The starting attitude requirement may not be met at low ATR fuel tank levels.

5.2.6.2 Technical Approach. The design guidelines for the fuel systm were:

o Provide fuel to:

- Main engine
- APU
- Smoke generator system

o Fuel capacity targets:

- ATR - 255 gallons
- Use existing (M1A1) front fuel tanks only

o Interface requirements:

- Main engine (850 lbs/hr at 4-22 psig)
- APU (35 lbs/hr at 4-22 psig)
- Smoke generator pump (560 lbs/hr at 0-10 psig)
- Electrical

  oo Fuel sensors
  oo Pump operation
  oo Pump sequencing

- Modes of operation:

  - APU only
  - Main engine only
  - APU cool down, main engine and smoke generator

- Fuel conditioning hardware integral to APU

5.2.6.3 Design Analysis. The ATR configuration relocates the current M1A1 production fuel water separator and primary filter to a fuel mounting plate on the main engine. Only one fuel disconnect on the fuel mounting plate is required for powerpack installation and removal.

A combination flow control and pressure reduction manifold is incorporated on the outlet side of the fuel water separator to reduce the engine and smoke generator system fuel pressure. This manifold is mounted to the fuel mounting plate on the engine resulting in an integrated modular design with the other major fuel conditioning components.

The manual shutoff valve is added to the fuel manifold to stop fuel flow to the engine. With this configuration, less fuel will be entrained between the engine and the valve after valve closure, resulting in a shorter period of time between valve closure and engine shut down compared to M1A1.

Two separate fuel pumps are necessary to satisfy the flow requirements of three unique systems. One pump provides fuel to the APU system at a maximum rate of 35 lbs/hr. The second pump provides fuel to the engine and the smoke generator systems at a combined rate of 1410 lbs/hr. Fuel to the engine is supplied at a maximum rate of 850 lbs/hr. The modified M1A1 smoke generator system is designed to operate at a maximum rate of 560 lbs/hr. This system was inoperative for the ATR.

The ATR fuel system was designed to comply with all existing M1A1 characteristics with the following exception:

- Under armor capacity (78 percent) not required for ATR.

- ATR starting attitude 60 percent longitudinal, 40 percent side slope - longitudinal (at low fuel levels).

- Range

- Fuel capacity

5.2.6.4 Tradeoffs

The following tradeoffs and analyses were developed.

- o Two fuel pumps versus one main fuel pump
  - One pump cannot meet flow extremes (35 lbs/hr to 1410 lbs/hr)
  - Additional fuel filtration is not required for APU
  - Pressure regulation is not required for APU

- o No day tank versus day tank
  - No fuel transfer or fuel level sensing systems required (systems required for day tank)
  - Maintainability (fewer components - easier access)
  - Cost (fewer components)
  - Less complex system (componentry and electronics)

- o Manifold versus line plumbing
  - Fewer interconnects (potential leaks)
  - Improved assembly
  - Reduced maintenance
  - Unitized component assembly

5.2.6.5 Selected Design. The selected fuel system design is:

- o Basic Fuel System
  - Fuel pumped directly from front fuel tanks
    - oo No day tank
    - oo No intertank fuel transfer system
    - oo New fuel manifold required for
      - Pressure Regulation
      - Flow Direction

- o Fuel Pumps
  - Two pumps (ATR peculiar)
    - oo APU Pump (35 lbs/hr)
    - oo Engine and smoke generator pump (1410 lbs/hr)

- o M1A1 Smoke Generator

- o ATR Fuel Capacity 255 Gallons
  - Front fuel tanks only

The fuel system compliances are:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Vehicle Fuel Capacity	255 Gallons	473 Gallons minimum (Dependent on vehicle configuration)
Underarmor Capacity (78%)	Not Required	Over 90%
Fuel Types	Same as M1A1	Same as M1A1
Emergency Operation - Provide Manual Fuel Shutoff	Provided	Provided
Starting Attitude - 60% Longitudinal, 40% Side Slope	Longitudinal at Low Fuel Levels Questionable for ATR	Same as M1A1
Starting Temperature Extremes - -25°F to 125°F Without Kit, Down To -65° with Kit	Sufficient for ATR Testing	Same as M1A1
Environmental	Sufficient for ATR Testing	Same as M1A1
Weight	Reduced	TBD

5.2.7 Electrical System. The vehicle electrical system consists of a power source, power control, and a power distribution system. A two-wire isolated return electrical system is used where the power ground wire is routed with the corresponding hot wire in a twisted pair to maintain electromagnetic compatibility.

5.2.7.1 Goals. The electical system goals were:

PARAMETERS	GOALS
o Power	24V DC, 300 amp-hour batteries, 650 amp oil cooled alternator Two (2) wire distribution
o Operation	18-30V DC
o Starting	-25°F to +125°F without kits, down to -65°F with kits

PARAMETERS	GOALS
o Silent Watch	Capable of starting at -25°F after one hour silent watch
o EMI/EMC	Same as M1A1
o Environmental	Same as M1A1
o Power Outlet	Same as M1A1
o Weight	Minimize weight increase
o Auxiliary Power	5KW, 28V DC APU
o Powerpack	Provide quick-disconnect panels to facilitate vertical powerpack removal
o Harnesses	Twisted pair, RFI shielding as necessary, coded per schematic diagram

5.2.7.2 Technical Approach. The ATR electrical design guidelines were:

- o Use existing NBC control system from tank commander's panel in the turret
- o Provide ability to switch automtically between APU and engine driven NBC system
- o Use existing lead acid batteries (6TN)
- o Use existing M1A1 hardware, where possible
- o All equipent/boxes shall be grounded to vehicle structure
- o Use same control/instrumentation except APU/SCAF
- o Provide fire safety improvements for electrical power system
- o Use prime power interrupter to protect batteries, power cables, and prevent fires
- o Electrical system must interface with the following subsystems:
  - Powerpack (engine/transmission)
  - CVT - Accessory drive gearbox
  - SCAF
  - Hydraulics

- APU
- NBC system
- Fuel system
- Fire suppression system

5.2.7.3 Design Analysis. The system power source consists of four MS35000-3 lead acid batteries (see below) in accordance with MS drawing 35000. These batteries are connected in series-parallel to provide 24VDC, 240 amp-hour capacity. With the APU running, the battery system provides sufficient electrical capacity to satisfy the engine cold starting requirementes of -25°F without a cold start kit, and -65°F with a cold start kit. In addition, the emergency (short duration) dormancy power requirement will be met.

Battery Characteristics

Type	Military type 6TL (lead acid)
Quantity	4
Battery connection	Series - parallel
Capacity (each pair)	120 amp hour
Voltage output	24vdc (alternator off)
Weight (each)	71 lbs.

A projected distribution of electrical loads is shown in Table 5-6. The charging system uses a 650 amp oil cooled alternator with a solid state voltage regulator (see below). With the CVT operating at a constant speed of 3000 rpm, the alternator delivers between 26.8 and 30.2 volts to the batteries when operated in an ambient temperature range of -65°F to +125°F, respectively.

Alternator Characteristics

Voltage	25.8 to 30.2 vdc
Output	650 amps - 28 volts @ 3000 rpm
Cooling	Oil
Flow	2.85 gpm min @ 2000 rpm
Weight	95 lbs
Special provisions	Waterproof

Two utility or auxiliary outlets are provided (24 vdc nominal), one each in the turret and hull. In addition, each outlet is provided with a 15 ampere automatic reset circuit breaker. A NATO slave receptacle will also be provided for standard slaving capability to/from other vehicles.

Table 5-6. TMEPS Electrical Load Analysis

PART NAME	SILENT WATCH ADDITIONAL TMEPS LOADS 24V AMPS	% DUTY	DUTY CYCLE AMPS	NORMAL 28V AMPS	% DUTY	DC AMPS	WORST CASE AMPS
APU, ECU & Fuel Sol. Display/Control	25.0	100	25.0	-	-	-	-
SCAF Drum Drive Motor	-	-	-	9.5	75	7.2	9.5
Electric Clutches	-	-	-	12.0	75	9.0	12.0
CVT ECU (Constant Velocity Trans.)	-	-	-	15.0	66	10.0	15.0
Flow Control Valve	-	-	-	2.0	100	2.0	3.0
Trans. ECU (Electronic Control Unit)	-	-	-	15.0	100	15.0	25.0
Misc. ANB, SCAF Cont/Display	-	-	-	10.0	100	10.0	10.0
Subtotal	25.0		25.0	63.5		53.2	74.5
M1A1 ELECTRICAL LOAD ANALYSIS							
Total Without Starter	138.2		77.0	374.5		218.1	662.6
TMEPS TOTAL LOAD ANALYSIS							
Total Without Starter	163.2		102.0	437.0		261.3	736.1
Starter Only				750.0 @ 60 sec			1850 @ 5 ms

Space claims have been verified for the following:

- o APU ECU
- o APU/SCAF Control Panel
- o Engine Disconnect Panel
- o APU Diconnect Panel
- o Batteries, Busses (Left Sponson)
- o Auxiliary Network Box, PPI, Regulators
- o Transmission Digital ECU
- o Diagnostic Data Readers (Engine and Transmission)
- o CVT ECU

5.2.7.4 Tradeoffs. The electrical subsystem design alternatives were evaluated and are presented herein.

Four (4) Lead Batteries versus Six (6) Batteries

- o (4) 6TL Batteries
  - Less space and weight
  - Less cables, clamps and terminals
  - Less maintenance
  - Less costly
  - Capability to start main engine with APU running at ambient temperatures less than -25°F

- o (6) 6TN Batteries
  - More space and weight
  - More hardware
  - More maintenance
  - More cost
  - Capable of starting main engine without APU running at ambient temperatures less than -25°F

A four battery system is integrated in TMEPS.

Single versus Two Alternators

- o Single Alternator
  - Driven from VAG overrunning clutch by either APU or main engine

- Single alternator can be controlled by one regulator
- Less expensive system
- More complicated alternator driving method
- Requires less space

o Two Alternators

- More expensive system
- Requires more space due to addition of hardware
- Requires two voltage regulators
- Less complicated alternator driving method

One alternator is integrated into the TMEPS design.

Battery Cable Connection versus Bus Connection

o Bus Connection

- Bus connection to battery terminals can cause misalignment under shock and vibration
- Misalignment may cause loose connection
- Loose connection to battery terminals may cause arcing due to presence of air gap
- Arcing may lead to battery fire

o Cable Connection

- More flexible connection than bus connection
- Prevents misalignment problem
- Better resistance to vehicle shock and vibration conditions
- Cable connection have proven to reduce fire hazards in M60A3 tank

TMEPS utilizes cable connections for the batteries.

Prime Power Interrupter (PPI Alternatives)

o With PPI

- Can protect batteries automatically
- Add protection to positive power bus, starter cables, alternator cables, cables to HPDB
- Power to auxiliary network box cannot be turned off without using PPI, since the auxiliary networks box is directly connected to positive power bus

o Without PPI

- No protection of batteries, starter cables, alternator cables, cables to HPDB

- Power to auxiliary network box cannot be turned off with master power switch

A prime power interrupter is an integral part of the TMEPS electrical design.

<u>Separate APU/SCAF Control Panel versus Modified (DMP/DIP)</u>

Driver's Master Panel (DMP)/Driver's Instrument Panel (DIP)

o Separate APU/SCAF Control Panel

  - No modification of DMP
  - Simple modification of DIP
  - More realistic design approach for ATR
  - Requires less electrical harness modification

o Modified DMP/DIP

  - APU/SCAF monitoring function can be added to modified DIP
  - APU/SCAF control function can be added to modified DMP
  - Requires redesign of DMP, DIP housing, face panel, mounting, PC boards, and harnesses

A separate APU/SCAF control panel is designed for the TMEPS ATR.

<u>Remote APU Control Panel versus Local APU Panel</u>

o Remote APU Panel/Display

  - Permits APU start/stop by the driver
  - Considered APU control from turret by commander and rejected due to lack of sufficient capacity in the turret slipring

o Local APU Control/Display

  - Inconvenient
  - No accessibility for the driver
  - Will not permit monitoring of APU

A remote APU control panel is located in the driver's compartment.

<u>Modification of Hull Networks Box (HNB) versus Separate Auxiliary HNB</u>

o Modify Existing HNB

  - Space for only six new circuit breakers

- Cannot accommodate eight additional new breakers
- No space for 10 new relays
- No space for adding three PC boards
- Require change of housing, cover, inside mounting, harnesses
- Require new connectors for harnesses

o Auxiliary Networks Box

- Very simple modification to existing HNB
- Less electrical harness modification required

An auxiliary networks box is integrated in the TMEPS electrical system.

Digital APU RPM Meter versus Analog Meter

o Analog Meter

- Cannot install in the available space in the APU/SCAF panel
- Experienced problem in M1 tank due to shock and vibration

o Digital Meter

- Requires less space
- Can be installed in APU/SCAF panel

A digital RPM meter is in the APU/SCAF panel.

5.2.7.5 Selected Design. The vehicle electrical power is provided by four MS35000-3 batteries and a 18KW alternator. The batteries provide basic power to the vehicle via the Auxiliary Network Box and Hull Power Distribution Box (Figure 5-44). Bus bar battery interconnects are replaced by cables to avoid Bus bar fires due to misalignment problems. In addition, increases spacing between the positive and negative buses is provided.

A positive regulator interlock control is added to ensure a smooth transition between APU and main engine opration. An additional feature which has been incorporated into the electrical system is the ability to activate the Auto-Trip for the Prime Power Interrupter (PPI) to disable the alternator field in case of a system short circuit.

The remote APU/SCAF Control and Display Panel (Figure 5-45) is located in the driver's compartment. The ECU for the APU has been located under the turret basket. The system block diagram is shown in Figure 5-46.

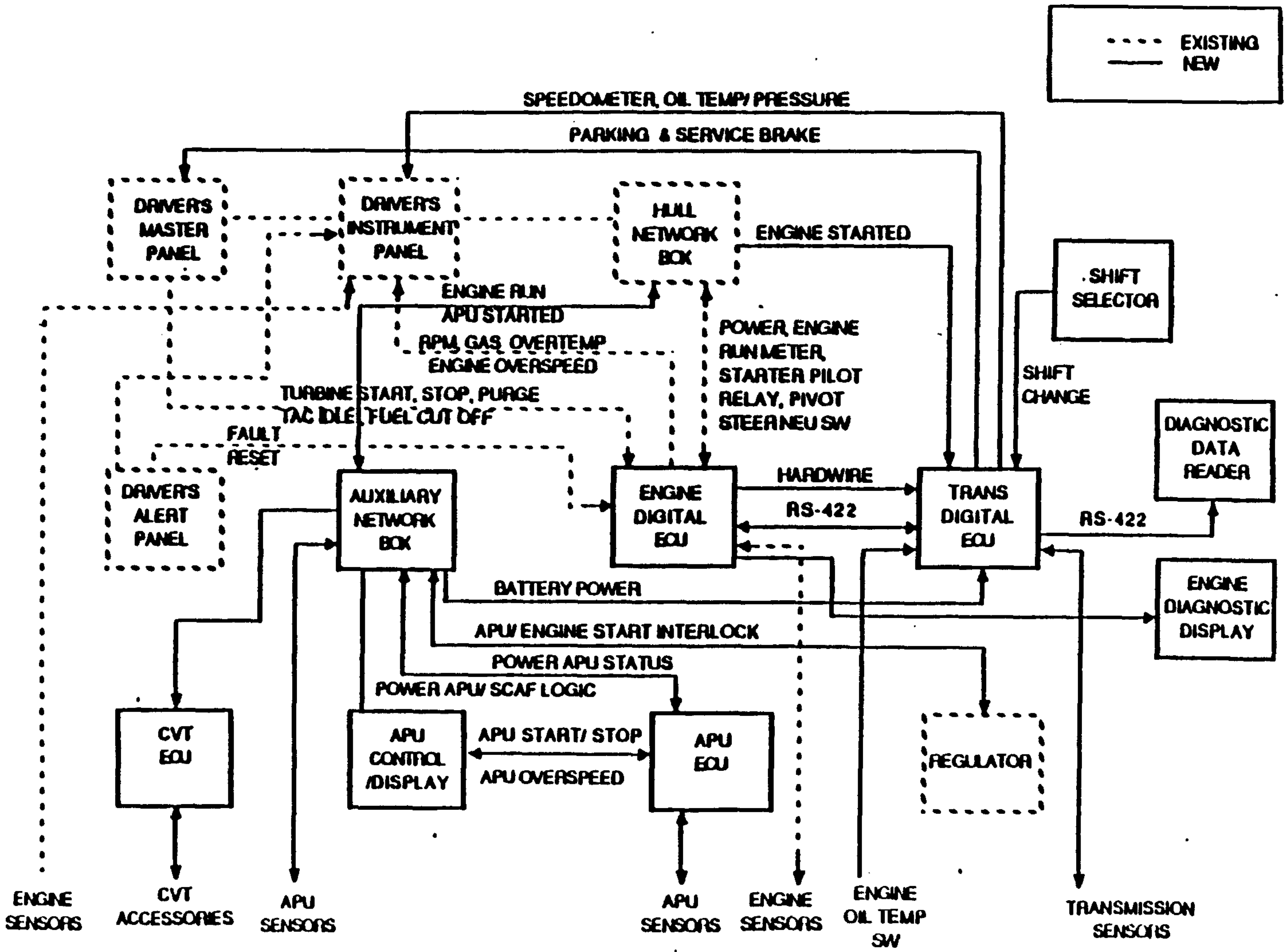


Figure 5-44. Vehicle Electrical Power Block Diagram

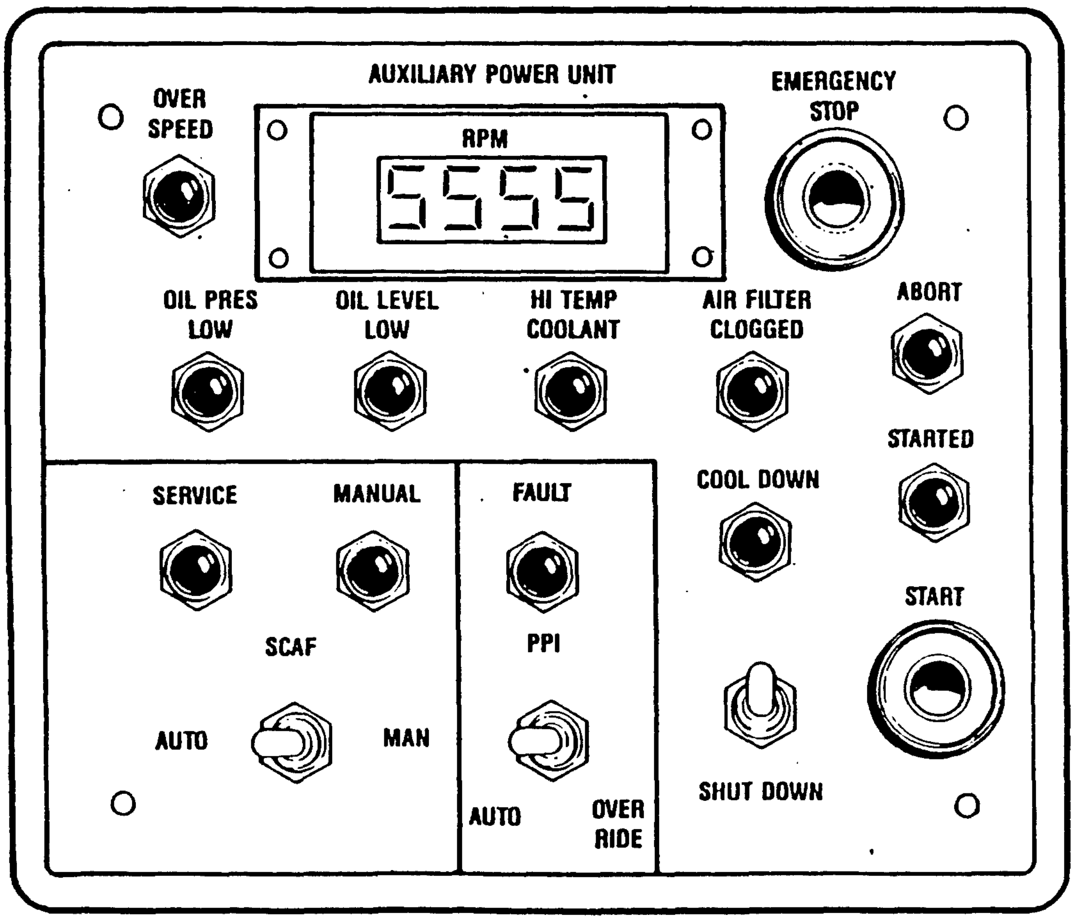


Figure 5-45. APU/SCAF Control/Display Panel

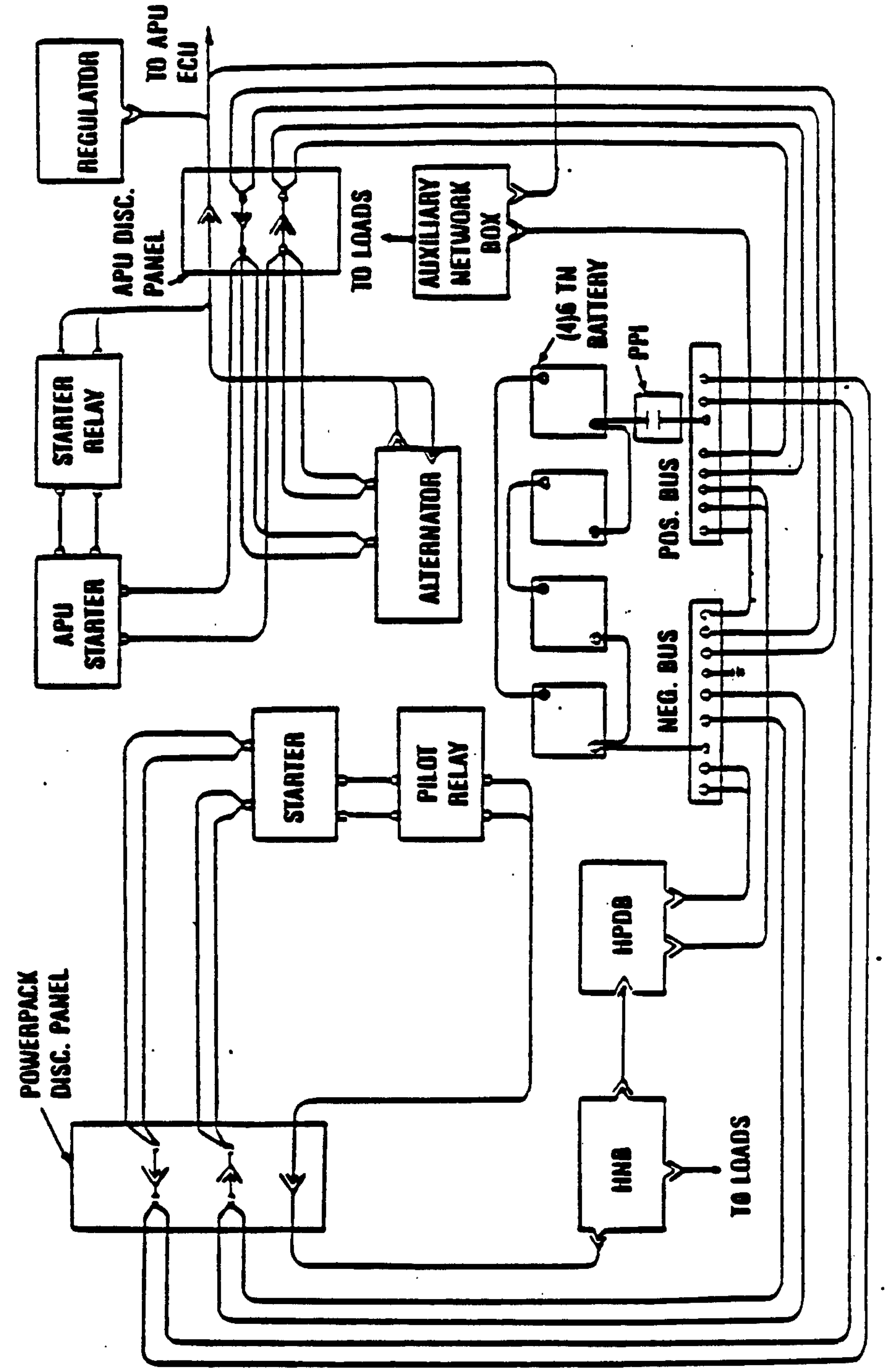


Figure 5-46. System Block Diagram

The design approach also includes the following Powerpack/SCAF/CVT features:

- o Electric controlled clutches in the VAG
- o Relocated modified quick-disconnect panel for the powerpack
- o New harness trough located on the engine
- o Automatic/Manual/SCAF auxiliary cleaning cycle initiation
- o SCAF plenum control box interface
- o Digital ECU for the main engine
- o Digital ECU for the transmission
- o Digital ECU for the CVT/VAG
- o RS-422 communication link between the engine and transmission ECUs with a hardwire backup

Fuel System - Electrical

The electrical hardware to control the fuel system was modified for the ATR configuration to reflect the following changes.

- o Revision of the fuel level sensor wiring in the sponson areas to accommodate removal of rear tanks
- o Revision of the left and right pump wiring circuits
- o Addition of the electrical circuit for the APU fuel pump
- o Addition of the smoke generator solenoid circuits

NBC System - Electrical

This system is modified to allow manual NBC system actuation after the APU or main engine starts. In addition, since the NBC system is co-powered, the CVT Electronic Control Unit controls engaging/disengaging of the NBC compressor clutch.

Fire Suppression and Detection System - Electrical

With the addition of the APU and subsequent supporting hardware, new wiring harnesses were designed to accommodate relocation of various fire sensors. New fire sensors, wiring, and amplifiers were also used. Should a fire develop and a second shot is required, automatic shutdown of the APU will occur.

Hull Networks Box

The Hull Networks Box required circuit revision due to modifications of the existing fuel and NBC systems, and the addition of a transmission digital ECU.

Driver's Instrument Panel

Wiring changes have been implemented to accommodate deletion of the sponson tank's fuel level sensors. Additional wiring changes have been made to allow the APU "caution" and "CVT fault" signals to be displayed on the panel.

Hull Power Distribution Box

Minor internal modifications have been made to accommodate the PPI.

Auxiliary Networks Box

Due to space claim constraints, the current Hull Networks Box (HNB), would not allow the addition of 14 new circuit breakers, 10 new relays, and 3 new Printed Circuit Boards (PCBs) required for TMEPS. A new Auxiliary Networks Box was designed and integrated to accommodate these required additions, Figure 5-47.

Wiring Harnesses

Twenty existing wiring harnesses required rework or redesign. Fourteen new harnesses were also required.

Electrical System Compliance

The electrical system compliances for the ATR were:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Weight Minimize Weight Increase	Insignificant Weight delta	Same as M1A1
Auxiliary Power 5KW, 28V DC	18KW, 28V DC	18KW, 28V DC
Powerpack Removal Provide quick-disconnect to facilitate vertical powerpack removal	Provided	Same as ATR

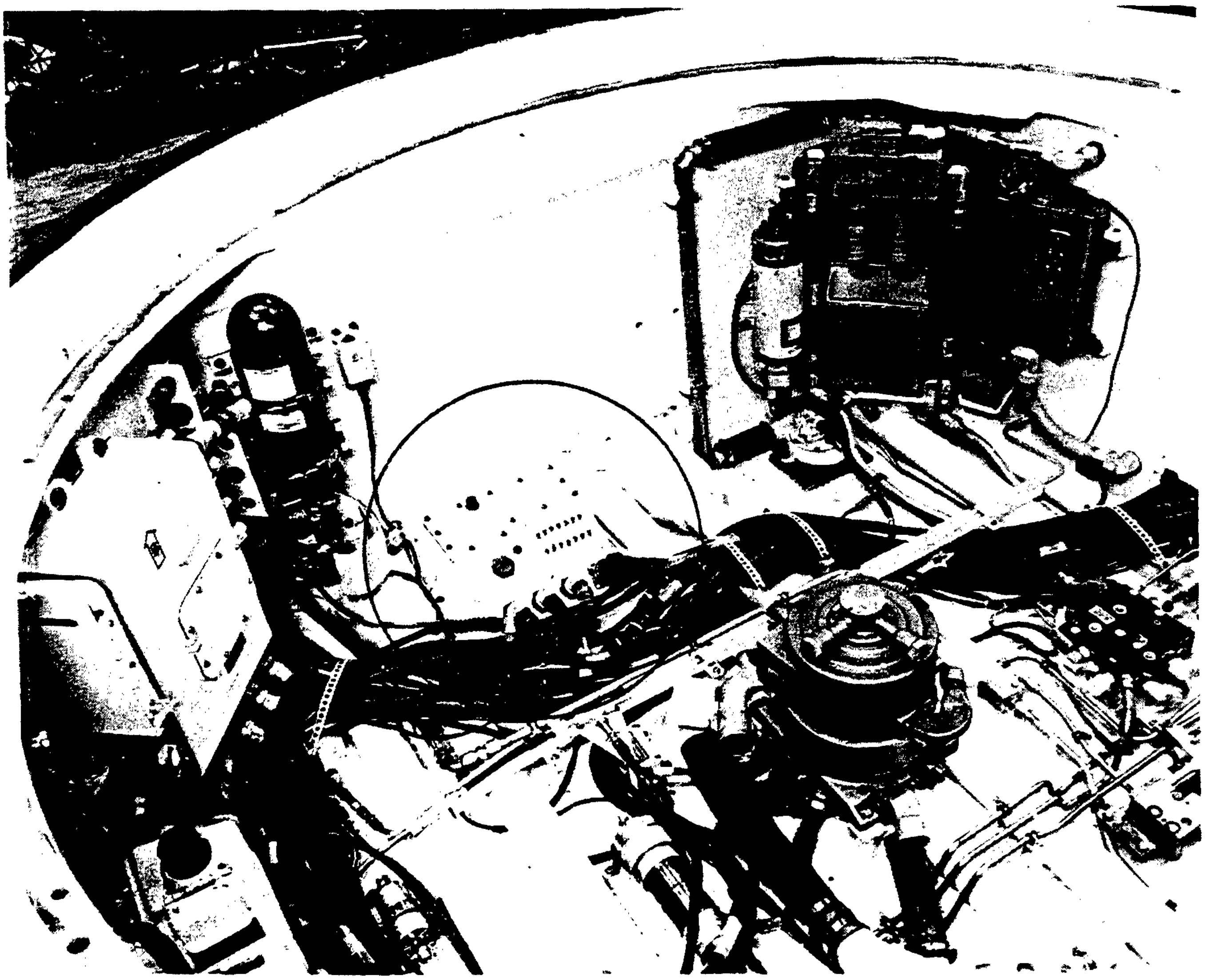


Figure 5-47. Auxiliary Networks Box

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Harnesses Twisted pair, RFI shielding (as necessary), coded per schematic	Same as M1A1	Same as ATR
Power 24V DC 300 AH (6) Batteries, 650 AMP Oil Cooled Alternator, 2 wire, 18-30V	24V DC 200 AH (4) Batteries 650A Oil Cooled Alternator, 2 Wire 18-30V Operation	Same as ATR
Starting -25°F to +125°F Without Kits, Down to -65°F with Kits	-25°F to +125°F Without Kits, Down to -65°F with Kits	Same as ATR
EMI/EMC Same as M1A1	Same as M1A1	Same as M1A1
Safety Same as M1A1	Improved	Same as ATR
Power Outlet Same as M1A1	Same as M1A1	Same as M1A1

5.2.8 Driver's Control System. The TMEPS driver's control system consists of steering, braking, throttle, and shift controls. For all driver controls, the configuration/hardware of the TMEPS driver's compartment is the same as the M1A1, including the forces required to operate the controls.

5.2.8.1 Goals. The driver's control system goals were:

	PARAMETER		GOAL
o	PARKING	-	Same as M1A1.
o	THROTTLE	-	Same as M1A1.
o	STEERING	-	Same as M1A1.
o	SERVICE BRAKE	-	Same as M1A1.
o	SHIFTING	-	Same as M1A1.

5.2.8.2 Technical Approach. The primary difference between TMEPS and M1A1 control systems was in the routing of the cables in the engine compartment. New cable routings were required for TMEPS.

During the development of the transmission controls system (see Section 5.2.2) an analysis was made in regard to the number of shafts to be employed for brake application. A two shaft system would have used one shaft for both service and left side parking brake functions; and the remaining shaft for the right side parking brake. A three shaft system, similar to the current M1A1 configuration (with respect to force and rotation requirements) was chosen to minimize the addition of new hardware design.

5.2.8.3 Design Analysis. The steering and brake control cables are mounted on the transmission. The braking and steering cables/linkages are the same as the M1A1, except for routing. The shifting and throttle controls are electrical connection with the engine and transmission ECUs. The throttle and shift controls are similar to the M1A1 configuration, with the exception of the electrical harness routing.

Control of the braking system is mechanical, with a large percentage of the brake system hardware identical to the production X1100-3B hardware.

The service brake and left parking brake (Figure 5-48) cables are routed from the top of the transmission down and under the engine. The steering control cable is routed down, behind the transmission, and fed under the transmission and engine. To facilitate the steer cable routing, a groove was designed in the transmission casting. Interference from the cooling and exhaust system prevented routing cables over the top of the powerpack on the left side. The right side parking brake cable is routed over the powerpack. This approach was selected to avoid the tight bends that would result if the cable were routed under the powerpack.

All cables are capable of being disconnected forward of the powerpack. Covered cables running from the bulkhead to the disconnects are secured to the hull and will stay with the vehicle during powerpack removal. Likewise cables mounted to the powerpack will stay with the powerpack.

5.2.8.4 Tradeoffs. A tradeoff study as conducted for a mechanical/hydraulic parking brake system (M1A1) vs. a hydraulic system (RAM-D). The M1A1 system was selected for TMEPS due to the following advantages over the RAM-D system:

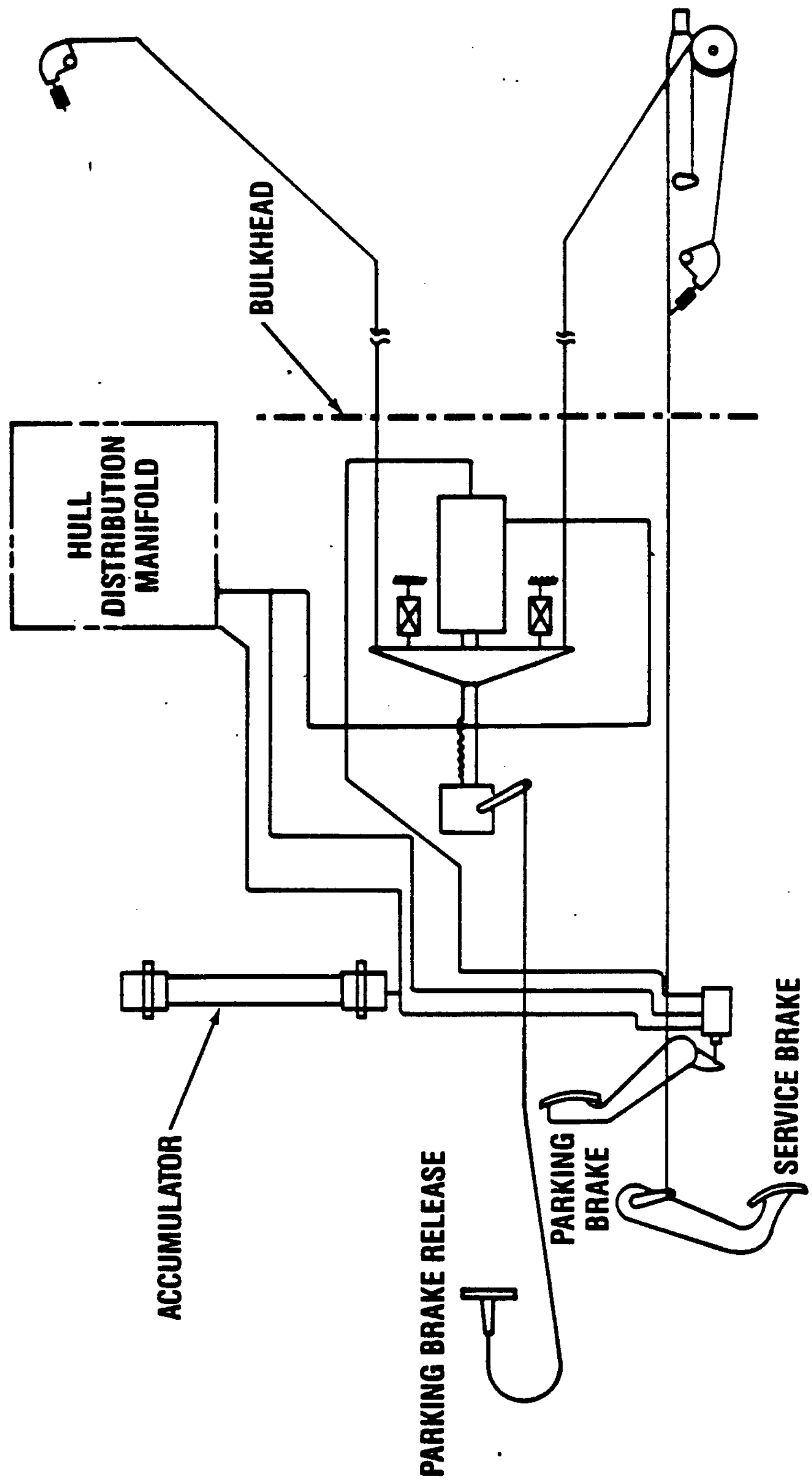


Figure 5-48. TMEPS Brake Control System

- Safety - No potential for engine compartment fire hazard
- Keeps all hydraulic components forward of the bulkhead
- Reduces technical complexity
- Uses conventional and economical off-the-shelf hardware
- Not subjected to heat/soak-back
- Reduces space claim
- Provides quick-disconnect; easy maintenance, and handling

5.2.8.5 Selected Design. The driver's control system selected concepts are:

- o Servicce Brake

  - Service brake configuration differs from M1A1 only in routing of the cables, location of the linkages, and the location of the brake shaft on transmission

- o Steering

  - Steering differs from M1A1 only in the routing of the cables, location of the linkages, and the location of the steer shaft on the transmission

- o . Parking Brake

  - Parking brake differs from M1A1 only in routing of the cable, location of the linkages, and the location of the parking brake shafts on transmission

Throttle and Shift Controls

- Throttle and shift controls will be similar to existing M1A1 configuration with the exception of the routing of electrical harnesses.

The driver's control system goals and compliances are:

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Controls such that a 5th percentile male operator may properly operate.	Same as M1A1	Same as ATR
Service Brake	Same as M1A1	Same as ATR
Parking Brake	Same as M1A1	Same as ATR
Steering	Same as M1A1	Same as ATR
Throttle	Same as M1A1	Same as ATR

GOAL	ATR-TMEPS	M1-TMEPS (FUTURE)
Shift	Same as M1A1	Same as ATR

5.2.9 Structures

5.2.9.1 Goals

PARAMETERS	GOALS
o Ballistic Protection	Same as M1A1 (space claim for ATR)
o Structural Adequacy	Same as M1A1
o Engine Compartment	Same as M1A1
o Access Doors and Grilles	Provide necessary access doors and grilles
o Vehicle Geometry	Same as M1A1 (except length)

5.2.9.2 Technical Approach. The M1A1 production hull structure (pilot vehicle 120-4) was modified to accommodate the TMEPS propulsion system. The ATR vehicle was not required to maintain ballistic integrity in the modified areas, since it will be used as a test bed, however, the space claim for ballistic protection is provided. To minimize cost, some parts were fabricated from mild structural steel instead of armor steel. This substitution did not affect the structural integrity of the hull.

The major structural design guidelines (Figure 5-49) were:

Top Deck

- o Provide space for Denver grilles
- o Provide sufficient support to modified top deck
- o Provide necessary grilles and access doors
- o Use existing M1A1 hardware wherever possible

Sponson

- o Design for the left sponson air induction, batteries and buses

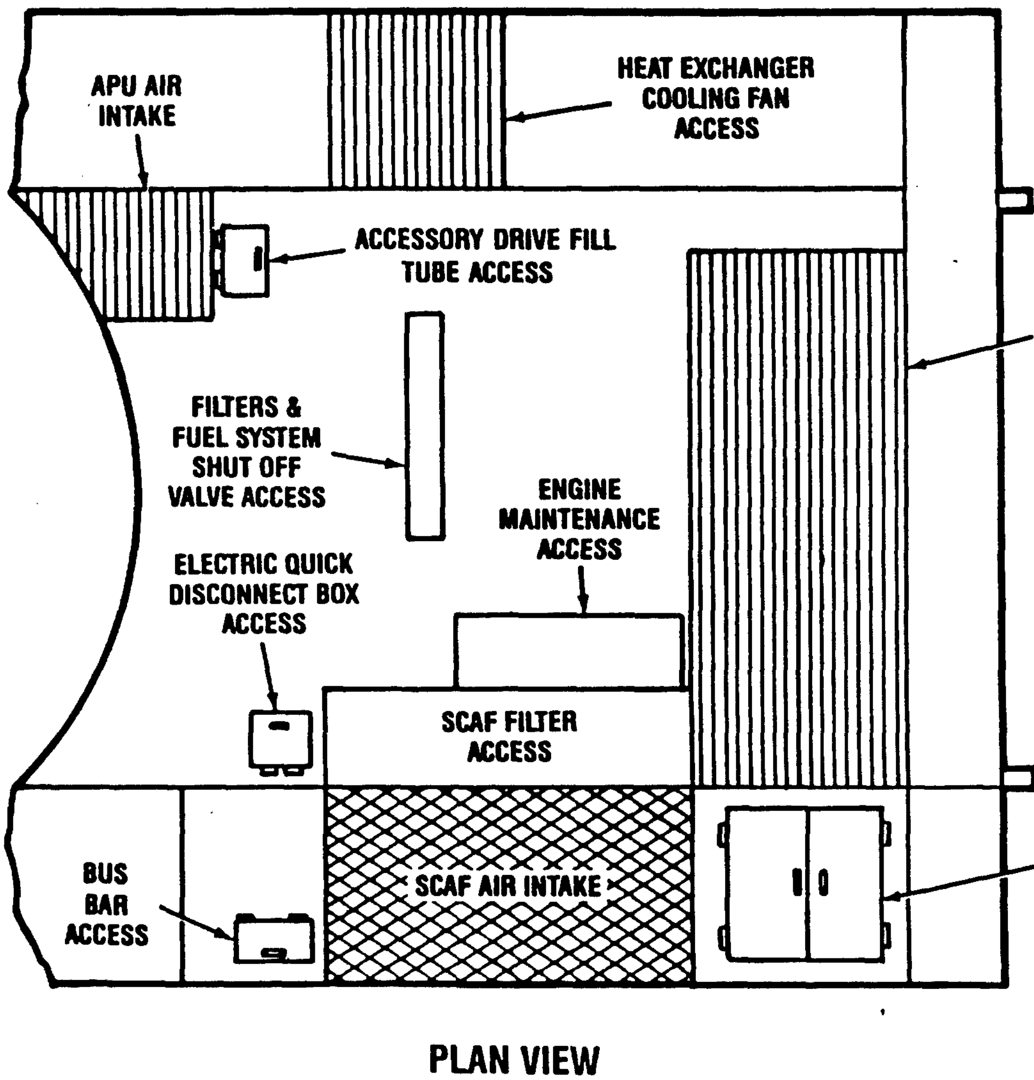


Figure 5-49. Structural Design Modifications

- o Design for the right sponson engine exhaust and auxiliary heat exchanger

Hull Structure (Figure 5-50)

- o Provide welded rear grilles for engine and oil cooler exhausts
- o Extend rear side walls to support rear grilles
- o Relocate lifting eyes and tail lights
- o Modify hull rear structure
- o Modify hull ammunition compartment and doors supporting structure for APU

Turret Basket

- o Modify turret platform hatch to facilitate new auxiliary network box installation

Weight

- o Minimize weight without degrading ballistic protection and structural adequacy.

5.2.9.3 Design analysis

- o <u>Hull Measurement Analysis</u>

  Dimensional measurements were taken inside the engine (pilot vehicle 120-4) to establish the minimum structure to facilitate design and location of the powerpack and other components. This was done using laser system which measured the vehicle engine compartment at specified grid locations. Measurements were also taken inside the engine compartment of 10 production vehicles at the Lima Tank Plant.

- o <u>Lifting Eye Analysis</u>

  The rear lifting eyes are relocated to accommodate the new engine exhaust design which exists through the right sponson rear wall, Figure 5-50.

  A preliminary stress analysis of the new design for the lifting eyes indicates that they are structurally sound.

  The new location of the lifting eyes does not accommodate the pin clearance on one side of the right

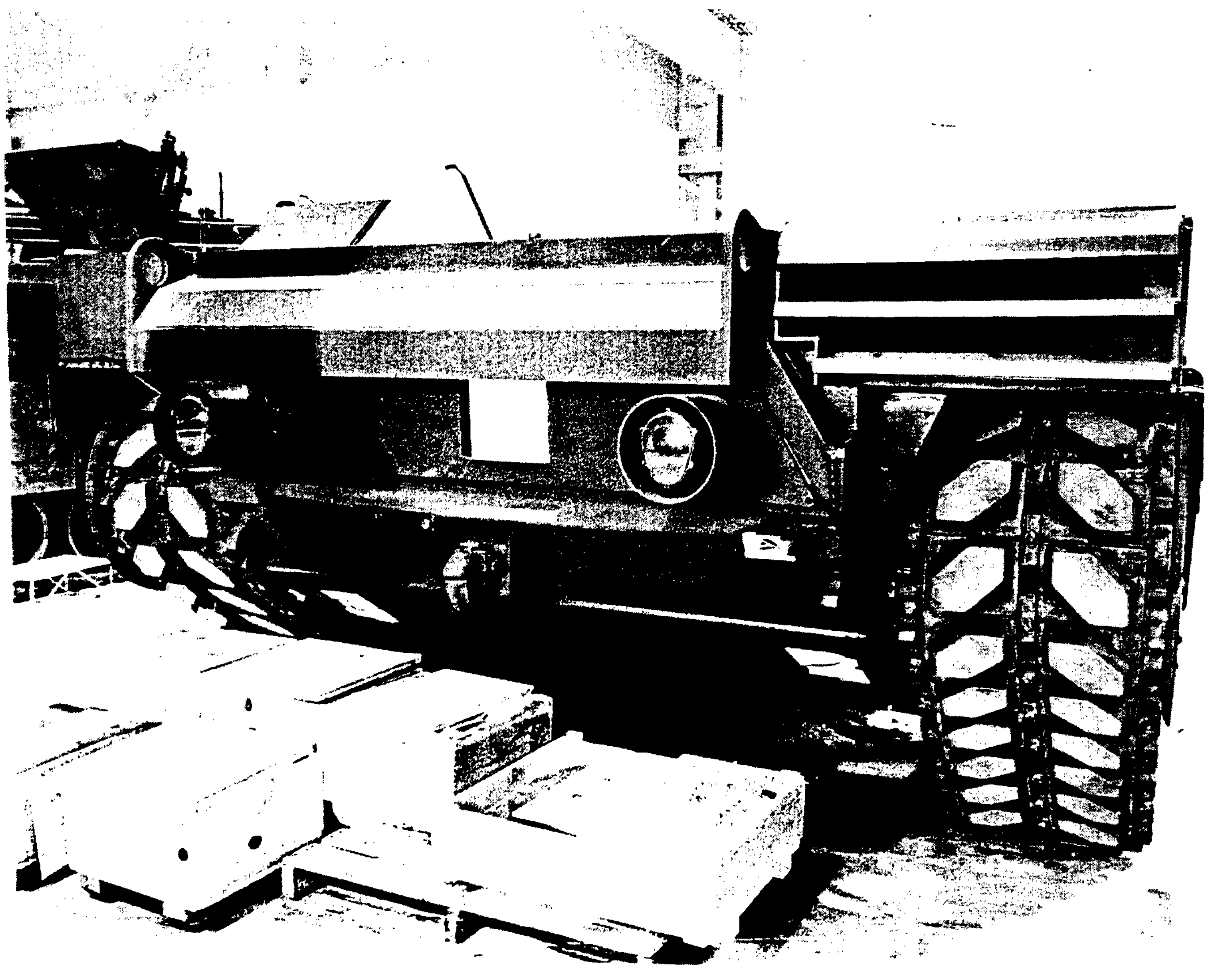


Figure 5-50. TMEPS Vehicle Rear View Configuration

lifting eye for slinging/lifting per MIL-STD-209 G. However, the pin can be inserted from the other side of the right lifting eye in the shackle, to lift the vehicle.

- Heat Signature Analysis

A preliminary heat signature review was performed on two different cooling exhaust grille designs, one with the airflow downward, the other rearward. TMEPS will proceed with the grille design which directs the exhaust air downward. The impact on heat signature will be addressed as a part of a follow-on program.

- Denver Grille Evaluation

The air intake grilles will protrude one inch above the top deck. This increased height would be addressed in a follow-on program to develop a shorter Denver grille. Preliminary ballistic evaluation shows that a shorter grille with narrower spacing between adjacent louvers can be used. Airflow and ballistic testing would be required to validate the new design.

- Hull Deflection Analysis

A hull deflection analysis was conducted to determine the degree of hull deflection when traversing Profile IV and the six (6) inch staggered bump course. The analysis was performed using an M1A1 hull with the top deck and rear grille doors installed.

The analysis indicates that the maximum relative displacement is negligible. In addition, the TMEPS hull is expected to be stiffer, due to the replacement of the M1A1 rear grille doors with a solid structure/grille assembly.

- Reaction Loads/Deflection Analysis

An analysis was performed to determine reaction loads induced by the engine/transmission combination on the trunnion supports, left and right side torque reaction members. In addition, the deflection at the engine mount and the shear force at the range housing was also determined. This data was used to design the engine/transmission support points, and attaching bolt clamping loads.

- **<u>Weight Analysis</u>**

  The ATR fully fueled weighed 120,900 pounds. This weight did not include crew or combat load. The actual increase in vehicle weight from the original M1A1 configuration was 300 pounds.

5.2.9.4 Tradeoffs. Trade studies were conducted in the following areas:

- Top Deck - One or two piece construction
- Denver grille versus new ballistic design versus M60 grille design
- Maintenance access doors - optimize access
- Lifting eyes - longer versus shorter (at new location)
- Tail light - hinged door versus fixed bolted door

5.2.9.5 Selected Design

<u>Top Deck</u>

The top deck was modified to provide access doors and air intake grilles with mounting similar to the M1A1.

<u>Left Sponson</u>

The left sponson fuel cell was removed and the structure modified to accommodate batteries, bus bars, and the SCAF air intake. Access to the four batteries is through two hinged top doors.

<u>Right Sponson</u>

The right sponson fuel cell and batteries were removed and replaced with the engine exhaust duct and auxiliary heat exchanger. In addition, the inner and rear sponson walls were also removed and the top deck extended to cover this area.

<u>Turret Basket</u>

The turret platform was modified to facilitate installation of a new auxiliary networks box.

<u>Hull Structure</u>

The following hull structural modifications were also required:

- The existing lifting eyes were relocated. Two side plates of the transmission cooling fan exhaust grille are used as lifting eyes. A torque box is also designed for the right hand lifting eye to transfer load to the hull wall.

- The existing tail lights from the rear of the sponson have been relocated on the new powerpack mounting access covers on the rear plate.

- The existing hinged rear grille doors are replaced by two separate welded grilles. The engine exhaust grille is at the rear right sponson. The bottom louver is detachable to facilitate track installation. The transmission cooling fan exhaust grille is located at the center of the rear plate to exhaust hot air downward. A vent hole is also provided to vent compartment air.

- A steer cable access door is provided on the rear plate.

- The hull ammo compartment inner wall and its door frame is removed to facilitate mounting and access to the APU.

- The inner and rear right sponson walls are removed to facilitate engine exhaust duct routing.

The vehicle structure goals and compliances are:

GOAL	AIR-TMEPS	M1-TMEPS (FUTURE)
Ballistic Protection (Protect Components)	Ensure Space Claims	M1A1 Equivalent
Structural Adequacy	M1A1 Similar	M1A1 Similar
Engine Compartment (Waterproof Bulkhead)	M1A1 Similar (Modify Bulkhead for TMEPS APU)	M1A1 Similar
Access Doors and Grilles	Design as Required	as required
Vehicle Geometry	M1A1 Equivalent (Except Length)	M1A1 Equivalent

5.3 Vehicle Performance

5.3.1 Performance Goals. The performance goals for the TMEPS ATR vehicle were to provide improved fuel economy, maintain or exceed M1A1 vehicle automotive performance (at 63 tons) and achieve M1 automotive performance (at 60 tons) where possible.

The TMEPS ATR vehicle with full fuel load, less crew, was weighed at 120,900 pounds (60.5 tons). Prior to testing, the vehicle was upweighted to 126,000 pounds (63 tons). Initial plans to test the vehicle at 130,000 pounds (65 tons) were abandoned, due to insufficient ballast storage space.

5.3.2 Automotive Performance. This section compares predicted TMEPS performance with actual measured data. Where possible, an explanation of performance deviation is provided.

Textron Lycoming has recently completed post calibration and diagnostic testing of engine T202 and the RESCAF used during the vehicle test. Additional testing and inspection of RESCAF is sccheduled to be completed by 30 October 1990. At that time, Textron will provide additional data and evaluation results.

5.3.2.1 Vehicle Acceleration. The time required to accelerate from 0 to 20 mph on a hard surface road with NBC system off and tactical idle on was measured in the forward direction only. Due to the transmission configuration, the vehicle would not obtain the M1A1 specified 20 mph reverse speed. Consequently, reverse acceleration time to 20 mph was not tested. A comparison of M1A1 specification and TMEPS measured acceleration data is provided below:

Time to 20 mph	M1A1[1] Minimum (Sec)	TMEPS[2] Measured (Sec)	TMEPS[3] Corrected (Sec)
	7.5	8.7	7.9

Notes: 1 Performance based on 63 ton vehicle, 90°F ambient, 2000 ft elevation.

2 Performance based on 63 ton vehicle, 60.5°F, 29.44 in Hg.

3 Acceleration time with back-up engine corrected for proper Engine Control Unit (ECU) and 63 ton weight. Performance based on 63 ton vehicle, 60.5°F, 29.44 in Hg.

The TMEPS ATR acceleration goal of 7.0 sec was not met. Subsequent investigation has ruled out the engine as the sole cause of the reduced performance. Results of this investigation presented in Section 5.3.2.2.

5.3.2.2 TMEPS Post Engine Investigation. The TMEPS program concluded in June 1990 with a one week vehicle demonstration at Milford Proving Grounds. The vehicle performed well but the mobility characteristics, most noticeably acceleration was lower than expected. Although there are many factors contributing to this performance, Textron Lycoming and Donaldson Company elected at their own expense, to further investigate the post test performance of the engine and SCAF filter elements. Accordingly, following the completion of the Milford testing, the engine (SN T202T) and the SCAF barrier filter elements were returned to Textron Lycoming in "as used" condition for further testing investigation. As a part of this investigation, the barrier filters were subsequently returned to the Donaldson Company for their independent assessment.

The testing at Textron Lycoming, illustrated in Figures 5-51 and 5-52, disclosed the following results:

Table 5-7. Engine Performance (Comparison)

Engine Condition At:	Date	SHP/	Ambient °F	Engine Inlet Temp. ( ) °F	NH
Acceptance Un-installed	Mar. 6	1541	69	71	100.6
Field Return Un-installed	Based on Sept. 21 Data	1498	69	71	100.6
Engine H.P.		43			

This engine, when installed in the vehicle and adjusted for losses imposed by inlet grill, exhaust duct and exhaust grill defined by GDLS and ambient/measured engine inlet temperature relationships, would produce power into the transmission as shown in Table 5.

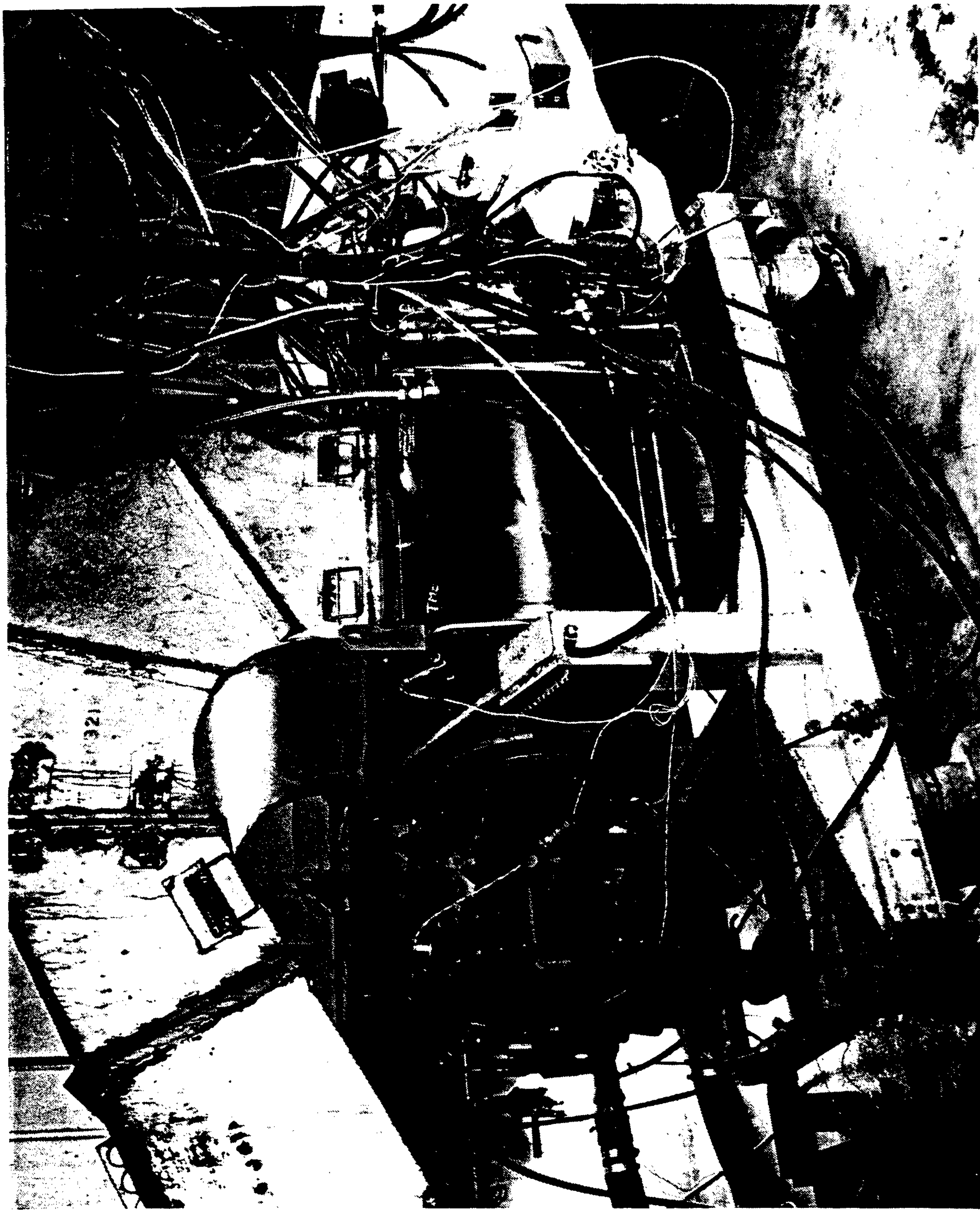


Figure 5-51. Test Cell Configuration

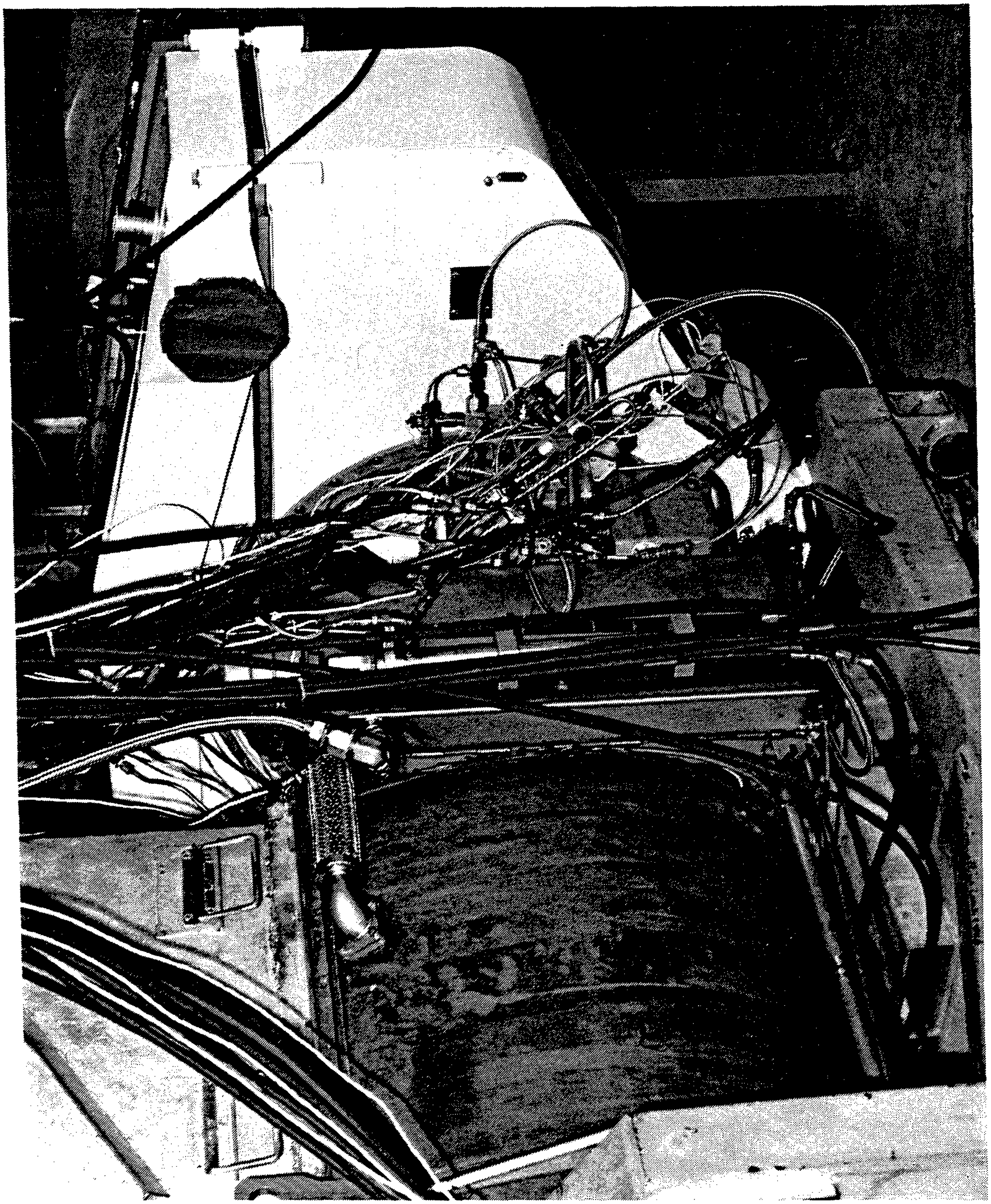


Figure 5-52. Test Cell Installation

Table 5-8. Engine Power in Vehicle (Installed)

	Filter Condition	SHP
T202T Engine	Clean	1358
T202T Engine	As Returned	1270
Reduction Due To Filters		88

Note: Engine only power reduction of 43 SHP is included in Table 5.

The field filters were returned to Donaldson Company for analysis, where Textron's pressure drop measurements and the abnormal oil contamination were confirmed. Donaldson also reported the filters have a substantial amount of carbon particles indicative of abnormally high exhaust ingestion (Figures 5-53, 5-54 and 5-55). Donaldson was not able to chemically identify the type of oil, but compared with their previous test experience with oil contamination, this oil has very high surface tension. The oil stain color (light yellow-green) is consistent with the Monsanto Santotrac 50 Traction Lubricant used in the Continuously Variable Transmission and the Vehicle Accessory Gearbox, which the GDLS engineers described as similar in color to the yellow-green of Prestone Anti-freeze. This traction type oil characteristically has a surface tension in excess of lubrication oil. Donaldson reported that engine oil on the other hand appears a more golden yellow color on filter media.

Although possible identification of the oil type is not available, the stain's color indicates the Santotrac 50 as the possible contaminant. GDLS reported there was a seal failure in the NBC compressor which is lubricated by Santotrac 50. Also, GDLS reported there was evidence of Santotrac 50 on the inlet to the SCAF. This further supports the possibility of Santotrac 50 being the source of the barrier filters contamination. However, without a definite analysis, we cannot rule out the possibility of other oil contamination possibly occuring during the test lab operation at Allison Transmission.

Analysis indicates that the 131 SHP reduction would be predicted to result in slightly less than a one second increase in acceleration time when adjusted for the conditions and vehicle weight that prevailed during the testing. This one second increase in acceleration time accounts for slightly less than half of the increase in acceleration time experienced at Milford Proving Grounds compared to the expected time.

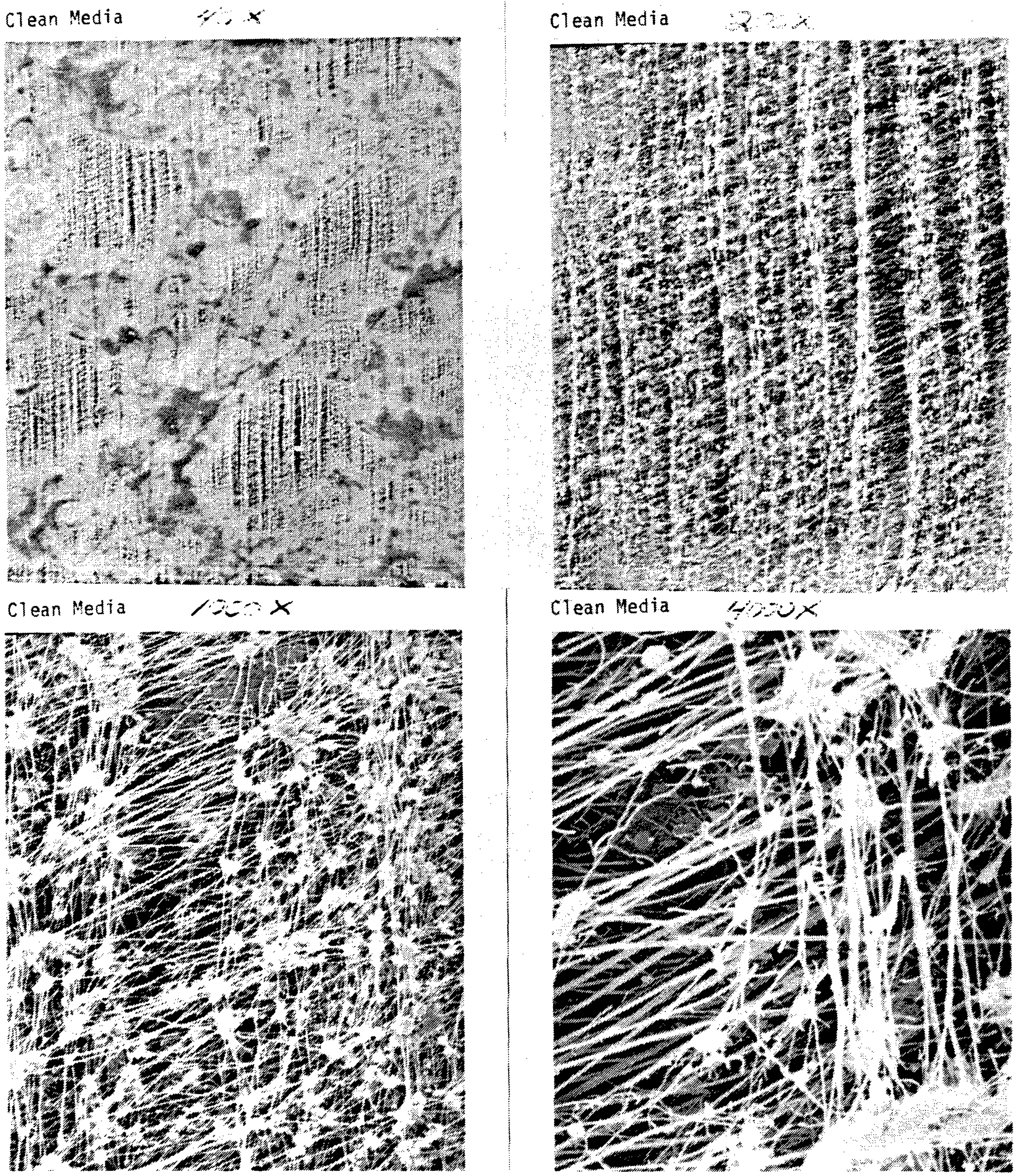
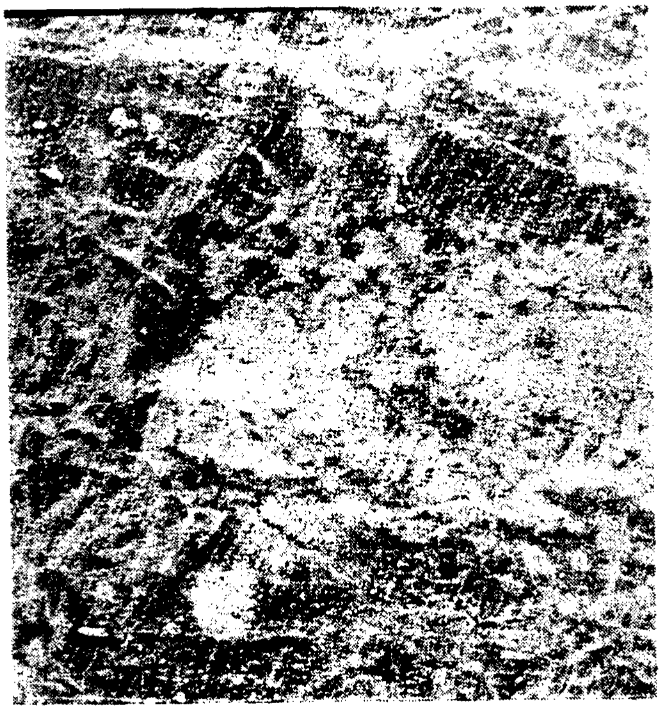


Figure 5-53. Clean Barrier Filter Media

Contaminated Media 40X -1



Contaminated Media -1

Contaminated Media 1000X -1

Contaminated Media 4000X -1

Figure 5-54. Contaminated Barrier Filter Media

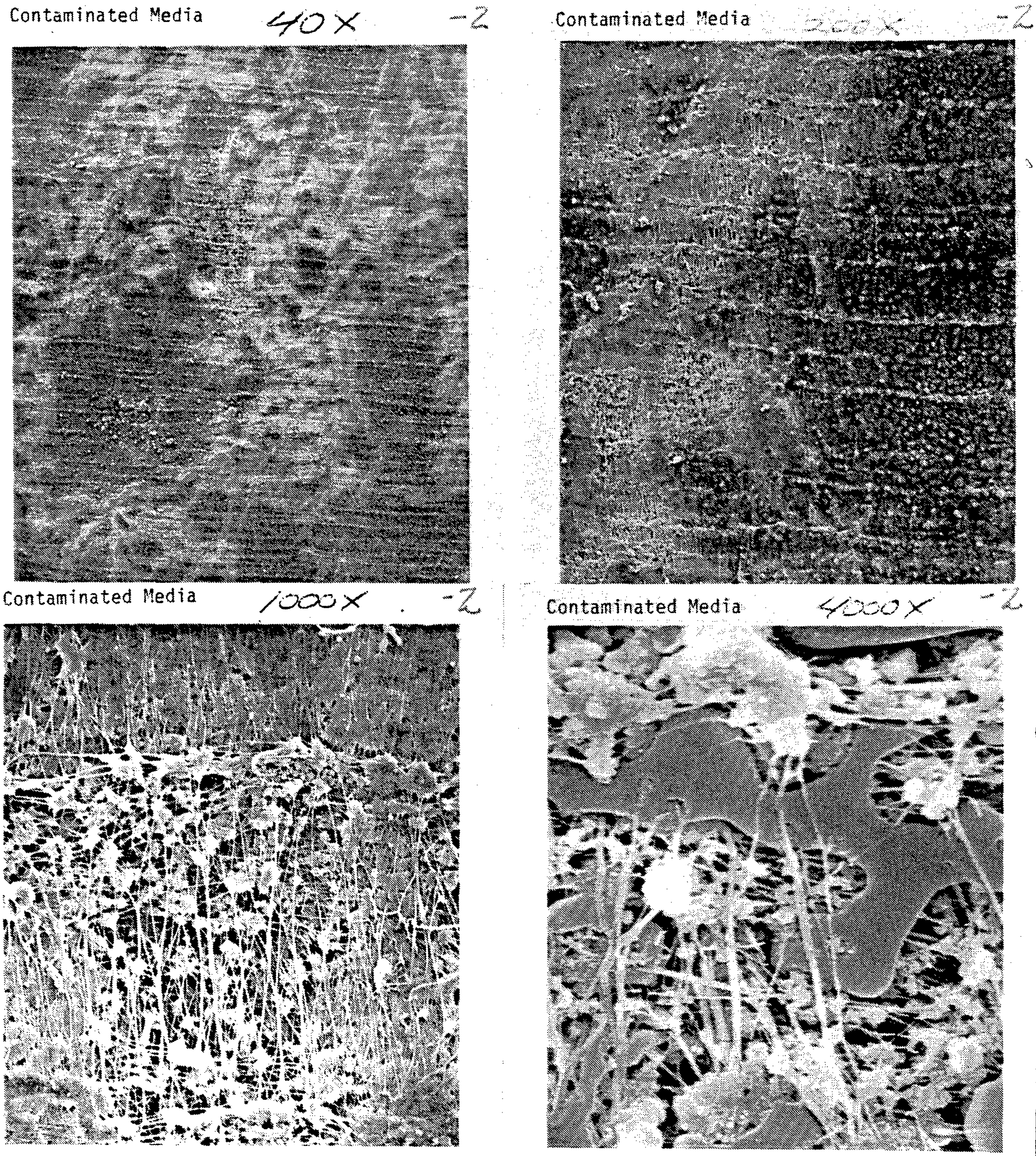


Figure 5-55. Contaminated Barrier Filter Media

At the conclusion of the field test, engine T202T and SCAF filter were returned to Lycoming for post test calibration. A new engine and filters were installed in the vehicle and a short experimental parking lot evaluation showed a recovery of aproximately one second in acceleration as well. Based on this, it is concluded that other portions of the system were also contributors to the acceleration time experienced.

1. Engine power was reduced by 43 SHP as a result of field operation; cause most likely dirty compressor.

2. SCAF pressure drop increased significantly as a result of field testing; cause most likely excessive oil contamination from an unknown source.

3. Total estimated engine/SCAF power reduction resulting from field test was 131 SHP.

4. 131 SHP reduction contributed about 1.0 seconds to the increased acceleration time experienced at Milford Proving Grounds compared with the expected time.

5. Other system losses contributed an additional 1.0 seconds to the increased acceleration time.

5.3.2.2 Vehicle Sustained Speed. Vehicle sustained speeds were measured on level hard surface road for forward and reverse vehicle operation with NBC system off. A comparison of vehicle data with M1A1 specification requirements is provided below:

Direction	M1A1[1] Minimum (MPH)	TMEPS[2] Measured @ 63 tons (MPH)
Forward	41.5	44.0
Reverse	20.0	12 mph[3]
Creep (forward)	<2.5	1.45

Notes:
1. Performance based on 63 ton vehicle, 90°F ambient, 2000 ft. elevation.
2. Uncorrected data at 63 ton vehicle 60.5°F ambient at 29.44 in Hg.
3. Transmission configuration limited max reverse speed to 12 mph.

5.3.2.3 Rolling Resistance. A rolling resistance test was performed with the final drives disconnected. This data indicated that the actual rolling resistance of the vehicle was less than projected. Actual and projected TMEPS ATR rolling resistance values are presented below:

Speed (MPH)	TMEPS Measured (16/ton)	TMEPS Projected (lb/ton)
5	73.0	78.6
10	82.5	89.0
15	95.2	107.7

5.3.2.4 Fuel Consumption. The vehicle fuel consumption was measured with the vehicle in tactical idle and also while traveling at 29 mph. These tests were performed on dry level road with NBC system off. Test results are presented below:

Vehicle Fuel Consumption

Speed (MPH)	TMEPS[1] 63 Ton (PPH)	M1A1[2] 63 Ton (PPH)
29	360.12	357.6
0 (Tac. idle)	89	104.48

Notes: 1. 60.5°F Ambient, 29.44 in. Hg.

2. 90°F, 2000 ft. elevation.

The TMEPS ATR demonstrated a significant reduction in tactical idle fuel consumption over the current M1A1 powerpack.

The APU fuel consumption was measured with the following approximate loads:

5KW Alternator Output	9 Hp load
Scavenge Blower on	3 Hp load
15 GPM, 1600 PSIG Hydraulic pump	16 Hp load
Vehicle Accessory Gearbox Spin losses	9 Hp load
Total Accessory load	37 Hp

Fuel consumption data is provided below:

APU Fuel Consumption

TMEPS[1] Measured (PPH)	TMEPS[2] Projected (PPH)
19.64	19.26

Notes: 1. 80°F ambient
2. 87°F ambient

5.3.2.5 Vehicle Steering/Handling. The TMEPS ATR was subjected to radius and pivot steering tests on level dry pavement. In addition, the vehicle was tested for level road drift. Level road drift is performed at 20 to 30 mph to determine the amount of lateral drift in 100 feet of travel. Test results are compared to M1A1 specification values below:

STEER/PIVOT/LEVEL ROAD DRIFT

TEST	M1A1 SPEC	TMEPS
Rt Turn	20 ft	11 ft 0 inch
Lft Turn	20 ft	11 ft 3 inch
Rt Pivot	39 ft	22 ft
Lft Pivot	39 ft	22 ft
Lateral Drift in 100 ft.	≤36 inch	5 inches

The TMEPS ATR was also operated on hilly cross country secondary road course. This test provided qualitative vehicle handling data from four separate drivers. The conclusion of the test was that the vehicle exhibited nominal steering characteristics throughout the course.

5.3.2.6 Auxiliary Automotive System Performance. The TMEPS ATR incorporated several auxiliary automotive systems which were tested concurrently with the automotive testing. These systems included the vehicle accessory gearbox, air handling, hydraulic, electrical and cooling systems. Proper operation of these systems was verified by onboard vehicle systems and related instrumentation. There were no auxiliary automotive system anomolies reported during vehicle testing.

5.4 Life Cycle Cost

5.4.1 Introduction. A Life Cycle Cost (LCC) assessment for the TMEPS program was performed. The analysis compared TMEPS to the two alternative vehicle configurations defined earlier: M1A1 1986 and M1A1 1991. The Operations Research Department at GDLS performed the analysis using standard methodologies and TACOM approved assumptions. A hybrid RCA PRICE and LOTUS spreadsheet model facilitated the costing process.

The LCC results portrayed in Figure 5-56 show the TMEPS configuration to be less costly than the M1A1 '86, yet predictably more costly than M1A1 '91. Development, production and support costs are segmented to show their respective contributions to total LCC. For a fleet size of 4320 vehicles, TMEPS is 4 percent more costly than the M1A1 '91, but 9 percent less costly than the M1A1 '86. Notice that the Operations and Support (O&S) costs illustrated for TMEPS and M1A1 '91 show significant savings over the M1A1 '86. These savings can be largely attributed to the presence of an APU in these configurations. See "LCC Results" for additional detail.

These results are very encouraging for TMEPS especially when factoring in the potential value of freeing up space in the tank. Other than generating O&S cost savings, the M1A1 '91 as an alternative has very little to offer. Its configuration while optional from an LCC perspective, is probably not the optimal design for the Abrams tank of the future.

5.4.2 LCC Methodology. A major challenge in formulating the methodology for this study was the issue of commonality and how best to consider it in the analysis. By the time TMEPS is fielded in June 1992, over 7,700 Abrams tanks will have been fielded with T-configuration powerpacks. At these quantities, commonality becomes a very important consideration.

In this analysis, each candidate configuration possesses its own degree of commonality with the fielded fleet. Part of the analytical challenge was to assess the commonality offered by the M1A1 '91 and TMEPS configurations, since these alternatives deviate from the configuration in the field. The M1A1 '86 is nearly 100 percent common with what is in the field by definition, while M1A1 '91 and TMEPS offer less than 100 percent commonality.

A careful study reveals that several hardware items/systems would be impacted with the implementation of TMEPS. Some of these represent LCC savers while others are LCC costers. Altogether, 21 separate elements have been identified and organized into hardware Work Breakdown Structures (WBS) for anlysis. Figure 5-57 details each of these elements. An

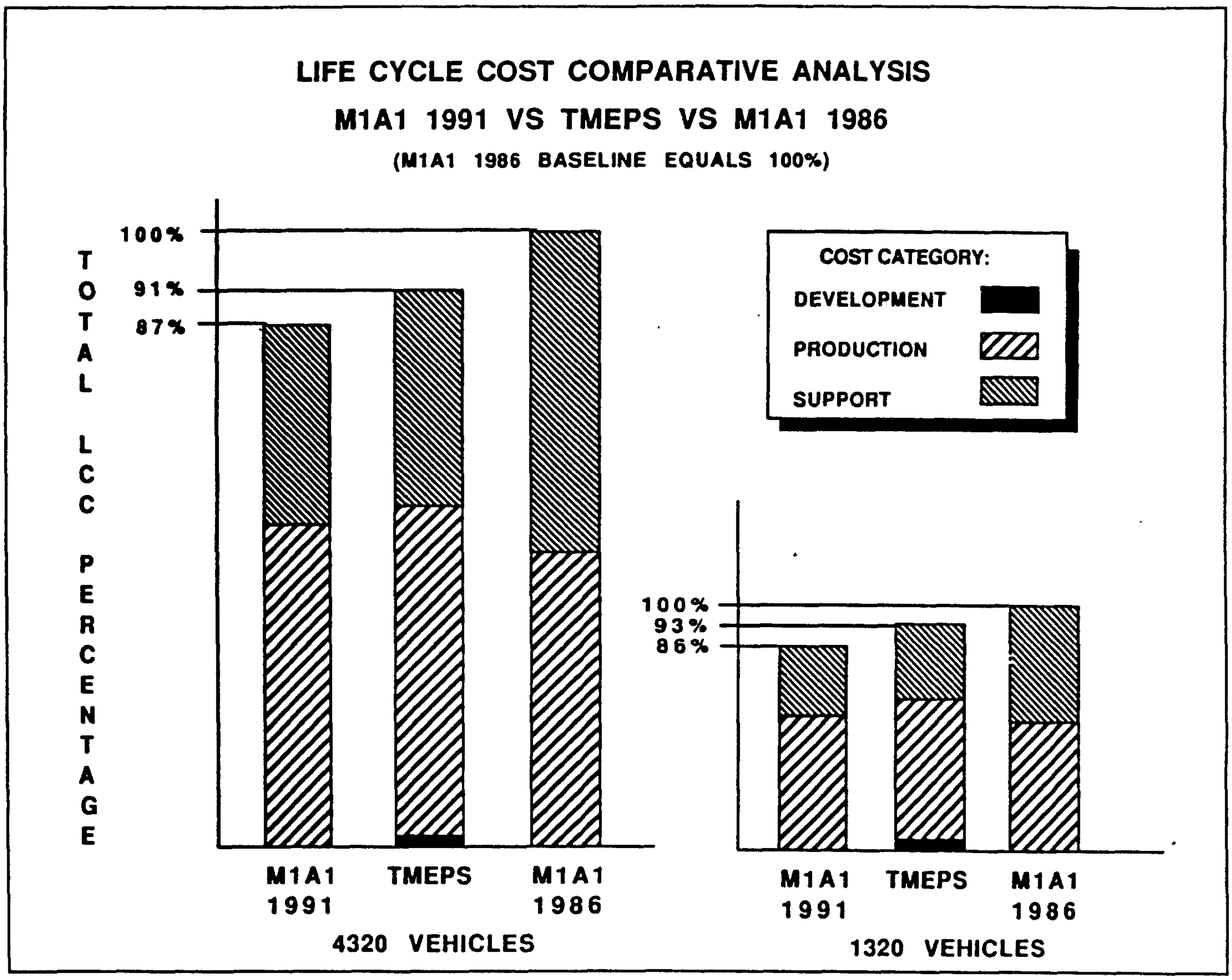


Figure 5-56. Life Cycle Cost Comparative Analysis, M1A1 1991, M1A1 1986 and TMEPS

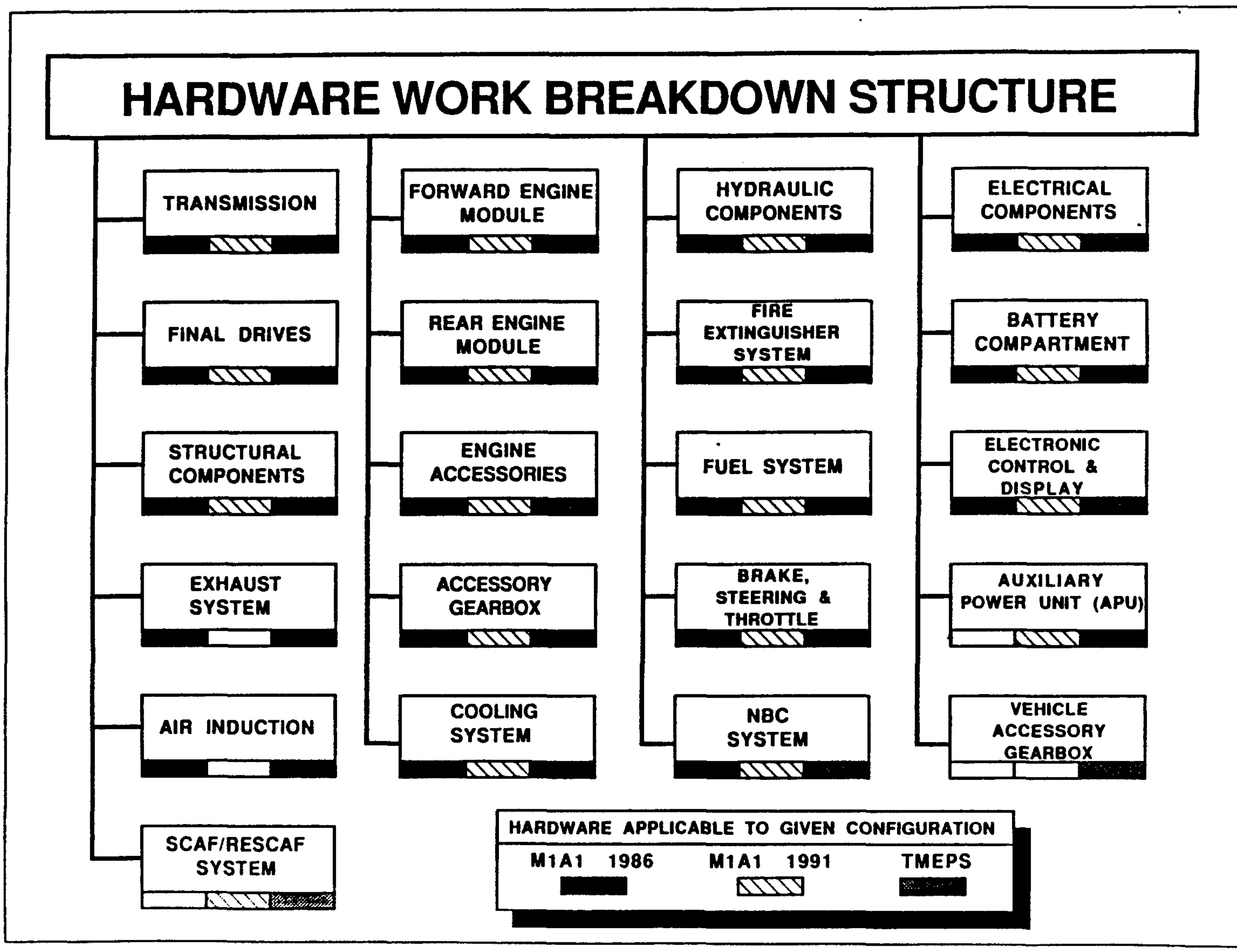


Figure 5-57. Hardware Work Breakdown Structure

analysis of the TMEPS configuration reveals that a great deal of commonality exists among the major cost drivers in the system. Even the transmission which is new is 46 percent common. Table 5-9 summarizes how the WBS boxes were categorized in terms of being unchanged, new or modified.

With the WBS established, two fleet size LCCs were generated: One at 1320 vehicles and another at 4320 vehicles. The approach used was to consider unchanged and modified hardware separately. If the box was labeled as unchanged, it was considered common with the fielded fleet. If the box was considered new or modified, commonality benefits/payoffs did not apply.

Figure 5-58 offers a fleet size and commonality perspective. By the assumed TMEPS deployment date of 1992, 7747 Abrams tanks would have been produced and deployed. Adding 1320 or 4320 vehicles to the fleet would encompass producing and deploying both common and unique hardware (except for M1A1 '86). Capturing the LCC for the common hardware at the 1320 fleet size was accomplished by generating an LCC at 9067 vehicles, another at 7747 vehicles, and then calculating the difference (9067 minus 7747 = 1320). This approach allowed the Operations Research Department to more realistically cost out production and support costs for the common hardware, since production economies and existing Army logistical support resources were taken into account.

The new and modified hardware, however, would not benefit from production economies, nor would there be any logistical support in place for them. Therefore, it was costed like any new item entering production and the Army Supply System. For the 1320 fleet size, this meant that these boxes in the WBS were evaluated at a 1320 production and sustainment quantity.

The 4320 fleet size was evaluated in exactly the same manner. The purpose of costing a larger fleet size was to quantify the LCC benefits of TMEPS through the end of Abrams tank production. Specifically, the focus was to show how O&S costs accumulate over time.

To support the implementation of this methodology, the RCA PRICE models were used in conjunction with a host of LOTUS spreadsheets. Figure 5-59 illustrates the modeling process from a global perspective.

The RCA PRICE models were used to calculate the majority of the development, production, operation, and support costs used in this interim LCC assessment. They were calibrated with average unit production cost estimates which were rigorously researched.

Table 5-9. Hardware Commonality

HARDWARE COMMONALITY

HARDWARE ELEMENT:	VEHICLE CONFIGURATION M1A1 1986	M1AI 1991	TMEPS
TRANSMISSION	UC	UC	N/M
FINAL DRIVES	UC	UC	N/M
STRUCTURE	UC	UC	N/M
EXHAUST SYSTEM	UC	N/M	N/M
COOLING SYSTEM	UC	UC	N/M
AIR INDUCTION	UC	N/A	N/A
REAR ENGINE MODULE	UC	UC	UC
ENGINE ACCESSORIES	UC	UC	UC
ACCESSORY GEARBOX	UC	UC	N/M
FORWARD ENGINE MODULE	UC	UC	UC
HYDRAULIC COMPONENTS	UC	UC	N/M
FIRE EXTINGUISHER SYS.	UC	UC	N/M
FUEL SYSTEM	UC	UC	N/M
BRAKES, STEERING ETC.	UC	UC	N/M
NBC SYSTEM	UC	UC	UC
ELECTRICAL COMPONENTS	UC	UC	N/M
BATTERY COMPARTMENT	UC	UC	N/M
ELECTRONIC CONTROL & DISP.	UC	UC	N/M
AUXILIARY POWER UNIT	N/A	N/M	N/M
SCAF/RESCAF SYSTEM	N/A	N/M	N/M
VEHICLE ACCESSORY GEARBOX	N/A	N/A	N/M

COMMONALITY STATUS WITH CURRENT FLEET
UC = UNCHANGED N/M = NEW/MODIFIED N/A = NOT APPLICABLE

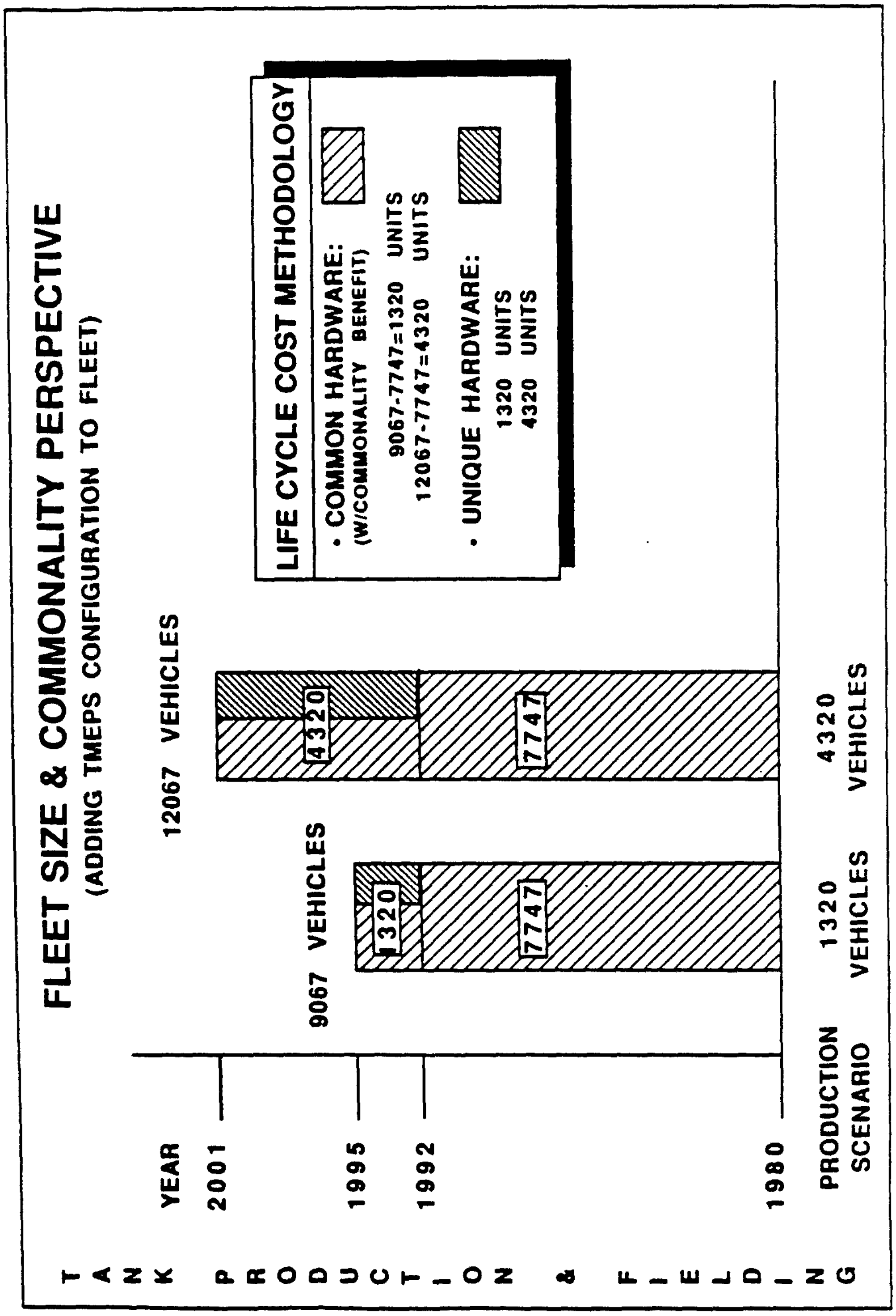


Figure 5-58. Fleet Size and Commonality Perspective, Adding TMEPS Configuration to Fleet

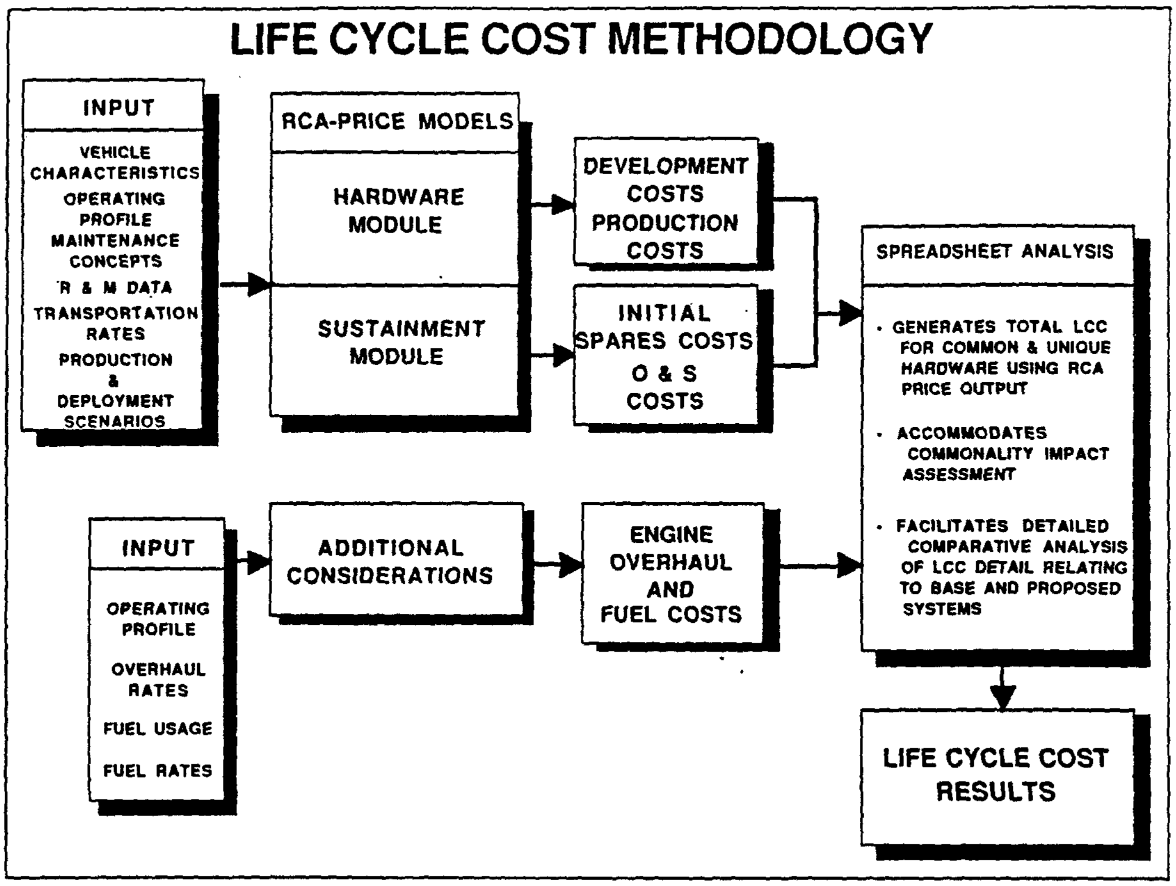


Figure 5-59. Life Cycle Cost Methodology

The majority of these AUPC estimates were obtained from actual vendor quotes or were estimated in-house by GDLS. All in-house estimates wre coordinated with the TMEPS Program Office. Elements which are normally not costed by the model were estimated using a series of LOTUS 123 spreadsheets. Training cost impacts were not assessed in these figures.

5.4.3 LCC Assumptions. The following key assumptions which were coordinated with the Government have been incorporated into the LCC analysis:

- o The support period for a TMEPS configured vehicle, an M1A1 '91 vehicle, and an M1A1 '86 vehicle, is 20 years.

- o Average peacetime annual operating tempo for high usage vehicles is estimated at 255.5 engine-hours or 934 miles per year. Average operating miles per hour is 3.66. Per agreement with TACOM, operation and support costs for low usage tanks are not included in this analysis. (TMEPS becomes even more cost competitive when these vehicles are considered.

		Percent of Fleet
CONUS	High Usage	38
Europe	High Usage	37
POMCUS	Low Usage	25

- o The LCC modeling assumed a Full Scale Engineering Development (FSED) start date of 1 March 1989 with a completion date of 1 October 1992.

- o One prototype TMEPS configured vehicle will be build during the Advanced Development phase. During FESD, nine prototype TMEPS configured vehicles with five spare powerpacks will be built.

- o All development costs for M1A1 '86 and M1A1 '91 are considered sunk.

- o TMEPS production program initiation is November 1991 with first article delivery date of October 1992 and a production completion date of:

  1320 vehicles - February 1995
  4320 vehicles - May 2001

- TMEPS production is assumed at a rate of 40 vehicles per month or 480 vehicles per year.

- No additional test equipment is needed to support a TMEPS configured vehicle.

- Table 5-10 summarizes the average unit production cost estimates used in this analysis.

5.4.4 LCC Results. The results of the analysis as summarized in Table 5-11 show the M1A1 '91 as the configuration offering the lowest total LCC to the customer. Its LCC for 4320 vehicles is 12.9 percent ($846 million) less than M1A1 '86 and 4.2 percent less ($253 million) than TMEPS. Its externally mounted APU, Self-cleaning Air Filtration System, and RAM-D improvements generate substantial O&S cost savings at a relatively modest production cost investment. On the downside, M1A1 '91 frees up no additional space for ammunition, fuel, or any other competing resource. As such, although it offers the lowest LCC, it may not be the most cost-effective alternative.

The TMEPS configuration, on the other hand, does free up a significant amount of usable space in the vehicle, as well as other tangible benefits. Its LCC though somewhat higher than M1A1 '91 is still less than M1A1 '86. Additional analysis should be performed to determine if the customer can benefit from the space TMEPS frees up. If the space can be used to enhance operational effectiveness, TMEPS may emerge as the most cost-effective configuration of the three. Like M1A1 '91, TMEPS is an O&S cost saver. In fact, relative to M1A1 '86, TMEPS generates more than $1 billion in O&S savings over a 20-year support period (for 4320 vehicles), largely because of its internal APU and improved reliability characteristics. These savings more than offset the larger investment in development and production TMEPS requires over the M1A1 '86. As a result, TMEPS possesses a lower total LCC.

Notice from the results that the major discriminator between TMEPS and the M1A1 '91 (at 4320 vehicles) is in the area of production. Included in the production cost category are all of the nonrecurring, recurring, engineering, data, system test and evaluation, and initial spares costs aplicable to each alternative. TMEPS as a configuration requires not only more hardware, but hardware which is more technologically advanced. The data gathering effort reveals that these requirements will necessitate both recurring and nonrecurring production cost investments at a level above that of the M1A1 '91.

Table 5-12 details the total LCC at 4320 units for each configuration. A review of these results provides additional perspective on how the total LCC accumulates for each candidate.

Table 5-10. TMEPS Average Unit Production Cost Estimate Summary by WBS

TMEPS AVERAGE UNIT PRODUCTION COST ESTIMATE SUMMARY BY WBS
M1A1 1986 VS M1A1 1991 VS TMEPS ATR

BOX #	WBS ELEMENT	M1A1 1986 COST	M1A1 1991 COST WITH APU	TMEPS ATR COST WITH APU	TMEPS ATR DELTA OVER/(UNDER) M1A1 1986 BASE	TMEPS ATR DELTA OVER/(UNDER) M1A1 1991 BASE
1	TRANSMISSION	$137,264.00	$137,264.00	$140,000.00	$2,736.00	$2,736.00
2	FINAL DRIVES (SET)	$23,088.00	$23,088.00	$16,000.00	($7,088.00)	($7,088.00)
3	STRUCTURE	$11,601.00	$11,601.00	$10,000.00	($1,601.00)	($1,601.00)
4	EXHAUST	$1,412.00	$0.00	$1,500.00	$88.00	$1,500.00
5	COOLING SYSTEM	$10,594.00	$12,184.00	$18,419.00	$7,825.00	$6,235.00
6	AIR INDUCTION	$6,667.00	$0.00	$1,950.00	($4,717.00)	$1,950.00
7	SCAF OR RESCAF	$0.00	$27,500.00	$25,000.00	$25,000.00	($2,500.00)
8	REAR ENGINE MODULE	$142,400.00	$151,289.00	$148,820.00	$6,420.00	($2,469.00)
9	ACCESSORY GEARBOX	$13,700.00	$13,700.00	$13,700.00	$0.00	$0.00
10	ENGINE ACCESSORIES	$21,912.00	$21,950.00	$24,985.00	$3,073.00	$3,035.00
11	FORWARD ENGINE MOD	$131,100.00	$133,341.00	$132,566.00	$1,466.00	($775.00)
12	HYDRAULIC COMPONENTS	$1,615.00	$1,615.00	$1,749.00	$134.00	$134.00
13	FIRE EXTINGUISHER SY	$4,077.00	$4,077.00	$4,280.00	$203.00	$203.00
14	FUEL SYSTEM	$7,397.00	$7,397.00	$7,597.00	$200.00	$200.00
15	STEERING, BRAKES ETC	$5,263.00	$5,263.00	$5,215.00	($48.00)	($48.00)
16	NBC SYSTEM	$31,755.00	$31,755.00	$31,467.00	($288.00)	($288.00)
17	ELECTRICAL COMPONENT	$9,359.00	$9,799.00	$13,755.00	$4,396.00	$3,956.00
18	BATTERY COMPARTMENT	$1,304.00	$1,304.00	$869.00	($435.00)	($435.00)
19	CONTROL & DISPLAY	$16,250.00	$17,340.00	$19,877.00	$3,627.00	$2,537.00
20	APU SYSTEM	$0.00	$12,000.00	$16,670.00	$16,670.00	$4,670.00
21	VAG/CVT	$0.00	$0.00	$16,560.00	$16,560.00	$16,560.00
						$0.00
	WBS COST TOTALS	$576,758.00	$622,467.00	$650,979.00	$74,221.00	$28,512.00

Table 5-11. Total Life Cycle Cost Results, M1A1 1991, M1A1 1986 and TMEPS

TOTAL LIFE CYCLE COST RESULTS

M1A1 1986 VS TMEPS VS M1A1 1991

1987 $M

1320 VEHICLE PRODUCTION SCENARIO

CONFIGURATION	DEVELOPMENT	PRODUCTION	O&S	TOTAL
M1A1 "1986"	SUNK	$999.259	$1,011.289	$2,010.548
TMEPS	$100.320	$1,149.075	$626.871	$1,867.266
M1A1 "1991"	SUNK	$1,092.110	$638.105	$1,730.215

4320 VEHICLE PRODUCTION SCENARIO

CONFIGURATION	DEVELOPMENT	PRODUCTION	O&S	TOTAL
M1A1 "1986"	SUNK	$3,276.127	$3,308.596	$6,584.723
TMEPS	$100.320	$3,702.776	$2,188.890	$5,991.986
M1A1 "1991"	SUNK	$3,573.787	$2,164.956	$5,738.743

5-12. Comparison of Total Life Cycle Cost, Cost Drivers/Cost Savers

COMPARISON OF TOTAL LIFE CYCLE COSTS FOR A 20 YEAR SUPPORT PERIOD
M1A1 "1986" VS M1A1 "1991" VS TMEPS
COST DRIVERS / COST (SAVERS)
COST SUMMARY BY WBS ELEMENT 4320 UNITS (1987 CY $000)

BOX #	WBS ELEMENT:	M1A1 1986	M1A1 1991	TMEPS	TMEPS DELTA OVER/(UNDER) M1A1 1986	TMEPS DELTA OVER/(UNDER) M1A1 1991
1	TRANSMISSION	$757,480	$756,935	$740,766	($16,714)	($16,169)
2	FINAL DRIVES	$116,415	$116,415	$88,602	($27,813)	($27,813)
3	STRUCTURE	$59,364	$59,364	$56,171	($3,193)	($3,193)
4	EXHAUST SYSTEM	$77,992	$0	$74,350	($3,642)	$74,350
5	COOLING SYSTEM	$107,478	$116,122	$138,883	$31,405	$22,761
6	AIR INDUCTION	$250,698	$0	$17,929	($232,769)	$17,929
7	REAR MODULE, ENGINE	$784,852	$815,366	$806,048	$21,196	($9,318)
8	ENGINE ACCESSORIES	$154,952	$138,063	$155,236	$284	$17,173
9	ACCESSORY GEARBOX, ENGINE	$78,605	$74,954	$77,450	($1,155)	$2,496
10	FORWARD MODULE, ENGINE	$983,921	$904,846	$892,492	($91,429)	($12,354)
11	HYDRAULIC COMPONENTS	$14,565	$14,565	$15,474	$909	$909
12	FIRE EXTINGUISHER SYSTEM	$30,818	$30,818	$32,737	$1,919	$1,919
13	FUEL SYSTEM	$226,921	$226,921	$214,307	($12,614)	($12,614)
14	BRAKES AND STEERING CONTROL	$147,690	$147,690	$139,756	($7,934)	($7,934)
15	NBC SYSTEM	$269,074	$269,074	$245,294	($23,780)	($23,780)
16	ELECTRICAL COMPONENTS	$159,493	$170,562	$276,946	$117,453	$106,384
17	BATTERY COMPARTMENT	$41,018	$41,018	$22,793	($18,225)	($18,225)
18	ELECTRONIC CONTROL AND DISPLAY	$103,149	$114,183	$125,584	$22,435	$11,401
19	INTEGRATION AND TEST (COMMON ITEMS)	$151,963	$153,202	$96,357	($55,606)	($56,845)
20	AUXILIARY POWER UNIT	$0	$367,823	$548,221	$548,221	$180,398
21	SCAF/RESCAF SYSTEM	$0	$225,184	$212,376	$212,376	($12,808)
22	VEHICLE ACCESSORY GEARBOX/CVT	$0	$0	$93,445	$93,445	$93,445
23	INTEGRATION & TEST (UNIQUE ITEMS)	$0	$7,551	$81,813	$81,813	$74,262
24	FUEL USAGE	$252,754	$183,825	$146,146	($106,608)	($37,679)
25	ENGINE OVERHAUL	$1,815,521	$804,262	$692,810	($1,122,711)	($111,452)
	LIFE CYCLE COST TOTALS	$6,584,723	$5,738,743	$5,991,986	($592,737)	$253,243

5.4.5 LCC Summary. The LCC effort presented herein was based on available data that could be obtained on prototype hardware designs. These designs were developed to support the TMEPS Automotive Test Rig and would be refined in subsequent follow-on development stages. Never-the-less the LCC did provide an analysis and perspective which was useful in optimizing the design and trade off decisions made during the conduct of the TMEPS program. The absolute values presented in this LCC study could be expected to change under the influence of a full FSED follow-on. These changes would generally be expected to be in the positive direction.

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